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**HIGHER EDUCATION POLICY, GRADUATE TAXES AND  
WEALTH DISTRIBUTION**

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# Higher Education Policy, Graduate Taxes and Wealth Distribution

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Sebastián Guarda Leighton

## Abstract

This thesis intends to shed light on the possible effects of higher education policy reforms on the distribution of wealth, specifically the implementation of free higher education, replacing tuition fees. A novel alternative for financing the reform is examined: a tax on the labor income of higher education graduates. The analysis is based on a quantitative OLG life cycle model, with heterogeneous agents, intergenerational links, incomplete financial markets, endogenous education decision, and general equilibrium in the determination of wages. The results indicate a slight decrease in wealth inequality, explained by an increase in enrollment, graduation and a smaller earnings premium for higher education.

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*“The most valuable of all capital is that invested in human beings”*

Alfred Marshall, 1890

# 1 Introduction

Higher education policy is very diverse throughout the world. For example, the U.S. and Norway take radically different approaches in financing tertiary studies.<sup>1</sup> While the U.S. relies heavily on tuition fees and 64% of the tertiary education expenditure comes from private sources (as opposed to public), this figure drops to 4% in the case of Norway. In this country tuition costs are fully covered by the Ministry of Education and Research and on top of that students are given financial support for their living expenses, but these policies result in a much heavier budget burden for the government. Under the framework proposed by Ansell (2008), the former would correspond to the Anglo-American system of higher education, and the latter to the Scandinavian system. Ansell argues that partisan politics is the main reason behind each country’s choice of the regent system. But what are the economic effects of choosing one over the other?

This question becomes especially relevant in the case of Chile, which is currently in transit from the Anglo-American to the Scandinavian system. And since differences in higher education are a major source of heterogeneity in expenditure and income for households, a reform which would change the entire system might have significant distributional changes. But, as government expenditure increases, steady state budget balance requires an additional form of revenue. An innovative proposal which has not been extensively analyzed in the literature is imposing a tax on the beneficiaries of such a reform: the graduates. And the selectivity of this tax could induce even further distributional change.

This thesis thus intends to answer the question: *Which would be the long term effects of implementing universal free higher education, financed with a proportional tax on graduates’ rents, on the distribution of wealth in Chile?*

For this task we build an overlapping generations model, with agents who optimally decide whether to enter higher education or not and who are heterogeneous in a number of relevant dimensions (age, assets, an idiosyncratic productivity shock, higher education, ability and transfers from parents). In the model financial markets are incomplete and thus liquidity constraints are relevant. Intergenerational links are a key feature, through

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<sup>1</sup>The difference between higher and tertiary education varies between countries. In this work, both are used indistinctly to mean all forms of formal education after secondary, be it vocational or general.

parent-child ability correlation and inter-vivos transfers. The government has a tax and higher education funding policy subject to change in the policy reform. The cost and quality of higher education is exogenous and constant, as modeling this aspect is not part of the objectives of this investigation. And finally, the economy is small and open, and thus subject to an exogenous international interest rate, but wages of different types of labor (which are imperfect substitutes) are determined endogenously in general equilibrium.

This model is based strongly on the work of Abbott et al. (2013), yet much simpler and more parsimonious. The methodology consists of first calibrating the model for Chilean data computing the steady state equilibrium before the policy. Then, altering the model structure to represent the policy reform (free higher education and a tax on graduates) and computing a new steady state. This second equilibrium is thus a simulation of the policy reform, and provides an estimation of its long-run effects on the economy.

We hypothesize that five mechanisms will alter the steady-state distribution of wealth because of the reform. First, it is argued that inter-vivos transfers to pay for a child's studies are uncertain expenses that induce precautionary savings, which are reduced once tuition fees are set to zero. Second, if education is paid by parents in a specific time in the life cycle, they save in order to smooth consumption in that period, which would not happen if the graduate tax is levied throughout the whole life cycle. Both these mechanisms indicate that asset holdings should fall after the policy reform. Are these economically relevant mechanisms? Keynes (1936) might say so, as they incorporate two of the eight savings motives mentioned in his work, which are summarized in Browning & Lusardi (1996). Namely, the *precautionary savings* motive against uncertain future expenses (the first in Keynes' list), and the *life cycle* motive: "To provide for an anticipated future relation between the income and the needs of the individual or his family different from that which exists in the present, as, for example, in relation to old age, **family education, or the maintenance of dependents**".

Third, agents with small transfers from parents will cease to be financially constrained: some will enter and possibly graduate from higher education, increasing the proportion of labor that is skilled. Fourth, the graduate tax could provide a disincentive to opt for higher education, especially if dropout rates are high. This mechanism works in the exact opposite direction of releasing financial constraints. And finally fifth: both these mechanisms become relevant for the wealth distribution in general equilibrium, because a higher proportion of labor with higher education will trigger a change in wages which will decrease the earnings premium, income gini, and wealth gini.

In order to investigate this matter, the rest of this work proceeds as follows. In section 2, the academic literature concerning methodology and the underlying economic mechanisms is reviewed. The following section completes the background of this thesis by providing context, statistics and stylized facts about Chile. Then, section 4 builds the model and explains the mechanisms at work. Section 5 details the calibration of the model and section 6 discusses the results of its numerical solution. Finally, section 7 concludes.

## 2 Literature

The frontline papers which are most closely related to this thesis, are those of Abbott et al. (2013), Krueger & Ludwig (2016), Bohaceck & Kapicka (2010), Johnson & Keane (2013) and Garriga & Keightley (2007). They study outcomes of educational policies in general equilibrium OLG Bewley models with intergenerational links.

Heterogeneous agent models with incomplete markets and idiosyncratic earnings risk are very useful in characterizing earnings and wealth distributions, as they include the concept of precautionary saving dependent on individual liquidity constraints. Bewley (1977), Huggett (1993), Aiyagari (1994) and Krussel & Smith (1998) are some of the most influential papers that popularized these so-called Bewley models. Over-lapping generations and life cycle models go as far as the foundational paper by Samuelson (1958) and even further, but their application in Bewley models was popularized by Ríos-Rull (1995) and Huggett (1996) to investigate intergenerational wealth accumulation.

Regarding the two intergenerational links used, it is useful to discuss each one separately. Inter-vivos transfers<sup>2</sup> are shown to be sizable (20% of aggregate wealth, and almost as large as inheritances) in the U.S. by Gale & Scholz (1994). Moreover, these authors as well as Kotlikoff & Summers (1981) support the hypothesis that wealth accumulation is mostly an intergenerational phenomenon, as opposed to the importance of the life cycle stressed most strongly by Modigliani (1988). Consensus in the literature has favored the estimate of Gale & Scholz who find that intergenerational wealth transfers are responsible for 60% of total wealth accumulation, as stated by De Nardi (2004).

Inter-vivos transfers are also one of the mechanisms which would explain the relevance of parental income and wealth in college attainment, as documented by Belley & Lochner

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<sup>2</sup>Transfers between the living, as opposed to bequests, in this case from parent to child.

(2007). And Becker & Tomes (1979) note that the first of intergenerational transfers is payment for the child's education: monetary transfers for other reasons usually happen after this has been taken care of. This is highly related to the long standing debate of liquidity constraints in education, initiated by Becker (1964) who argued for their existence and relevance. However, modern evidence tends to favor the opposite in the U.S., as Cameron & Heckman (1998), Keane (2002), Garriga & Keightley (2007), Bohaceck & Kapicka (2010) all favor the hypothesis that financial constraints play a relatively minor role in tertiary educational decisions. The evidence for Chile is reviewed in section 3.

But, if inter-vivos transfers can't explain intergenerational correlation in education attainment (evidence presented in section 3 of this work), then parent-child correlation in ability is the next alternative in line. Sacerdote (2002) and Plug & Vijverberg (2003) present evidence for correlation in innate ability, which means genetics is relevant. Restuccia & Urrutia (2004) later build on this and add acquired ability, the accumulation of which happens at primary and secondary education, and is also highly correlated between generations of the same household. For this reason, most modern OLG models studying educational policy feature this variable and its intergenerational correlation.<sup>3</sup> In the highly parsimonious model used, ability is defined as the human capital accumulated up to the point of completing secondary education, understanding human capital in the classical and broad sense given by Becker (1962). Ability is also a crucial heterogeneous state variable because the enrollment increase of educational policies may consist of lower ability students, which would be more likely to drop out. Therefore ignoring this dimension biases upwards educational attainment estimations, as noted by Cameron & Heckman (1998) and Akyol & Athreya (2005).

The second heterogeneity in human capital modeled in this work is between skilled and unskilled labor: those that attained higher education (HE) and those that did not. And as this is a macro model intended to evaluate country-wide policy change, the model features general equilibrium in wage determination. A growing number of authors implement this aspect<sup>4</sup> and a big question arises: How much of the increase in enrollment due to education subsidies found in partial equilibrium holds for the general equilibrium case? Because if education subsidies increase the share of labor that is skilled, then the corresponding wage premium will fall, which is a disincentive towards education, known as the Stiglitz (1982) effect. Interestingly, this is not a settled matter. A tuition subsidy

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<sup>3</sup>Examples are Garriga & Keightley (2007), Bohaceck & Kapicka (2010), Abbott et al. (2013), Krueger & Ludwig (2016).

<sup>4</sup>Heckman et al. (1998a,b,c), Lee (2005), Lee & Wolpin (2006), Johnson & Keane (2013), Abbott et al. (2013), Krueger & Ludwig (2016).

mostly affects the wage premium in Heckman et al. (1998b) and makes little difference for college attendance, the opposite result in Lee (2005), and a midpoint in the case of Johnson & Keane (2013). The key in the different results is the elasticity of substitution between the different kinds of labor<sup>5</sup> (higher for Lee) and the structure of the model's labor market, which is the main contribution of Johnson & Keane who may have the most reliable estimate.<sup>6</sup>

Moving onto more of the model's characteristics, tax structure effects have a vast literature even in Bewley models alone, notable examples are Chamley (1986) and Judd (1985) and linked to education are Heckman, Lochner & Taber (1998c) and Krueger & Ludwig (2016).<sup>7</sup> The latter characterize the optimal degree of income tax progressivity and tertiary tuition subsidy, and find both policies to be complements by negating education decision distortions, and substitutes in providing social insurance. Their work and literature review demonstrate how interrelated both policies are, implying they should be modeled together. However, the graduate tax used is quite rare in academic literature and nonexistent in Bewley models up to the author's knowledge, which is one of the aspects that differentiate this work from any other done previously. It is relevant to analyze this policy reform in a Bewley model because they are arguably the best at characterizing wealth distributions.

Nevertheless, the previous literature on graduate taxes has interesting things to say. The two most influential papers addressing it make opposing policy recommendations. García-Peñalosa & Wälde (2000) argue that it achieves efficiency and equity considerations while at the same time diminishing the lifetime income risk of educational investment, but Greenaway & Haynes (2003) make practical arguments such as potential brain drain<sup>8</sup> to prefer income-contingent loans. On the latter's side are Espinoza & Urzúa (2015) who provide the previous arguments and more: for example those who don't graduate will receive the benefit of free higher education but won't have to pay taxes, causing

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<sup>5</sup>See Katz & Murphy (1992) or Borjas (2003).

<sup>6</sup>They make distinctions of up to 160 types of labor, differentiating by education, gender, age and occupation, and argue that this characterization is relevant because it reveals wage premium patterns that are much more complex than those usually studied by the literature. They base this structure on Kambourov & Manovskii (2004a,b, 2005) among others who argue that occupation may be a better measure of skill than education. Unfortunately to make this thesis' model parsimonious it misses out on that richer structure, and is subject to the pertinent criticism.

<sup>7</sup>Most of these models incorporate endogenous labor supply, which is relevant as taxes may distort the labor/leisure decision. Unfortunately the model does not incorporate such a feature in the pursuit of simplicity. This means a graduate tax could diminish labor supply from skilled workers and weaken the general equilibrium mechanism, but this is not incorporated in this thesis.

<sup>8</sup>They also mention the long time needed to achieve steady state in the tax collection, and the impossibility in the UK to tie this tax reform to the education reform intended.

graduates to pay more in taxes than what they save in tuition fees.<sup>9</sup>

Parallel to the extensive line of study presented, the literature on explaining the wealth distribution has made extensive use of Bewley models. De Nardi (2015) makes a fine review of these papers, broadly qualified into five categories: High earnings risk for top earners would explain abnormally high saving rates for the wealthy, as in Castañeda et al. (2003); entrepreneurship and borrowing constraints are the key according to Quadrini (2000); Krussell & Smith (2008) propose heterogeneity in patience, the richer being more patient; Hubbard et al. (1995) explains the bottom of the distribution with social insurance policies; and De Nardi (2004) herself models intergenerational links, but only through bequests and productivity inheritance. None of these authors consider tertiary education expenses as a significant savings motive, and none of the literature mentioned in the previous paragraphs focuses on the effects on the wealth distribution. The purpose of this investigation is to join these two separate strands of literature, using graduate taxes as a means of financing the reform, and in the Chilean context which would be specially suitable as argued the next section.

## 3 Chilean Context

### 3.1 Benchmarks

A rough comparison of some interesting present statistics for Chile and three benchmarks is presented in the following table.<sup>10</sup> The U.S. is included for its Anglo-American system of higher education, and Norway for its Scandinavian system. The OECD is included as the only average of countries available for most of these statistics.

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<sup>9</sup>This is the only argument against graduate taxes that the model is able to incorporate due to its simplicity. Refer to the mentioned investigation for the rest of the criticism and thus shortcomings of this thesis.

<sup>10</sup>Appendix A provides detailed definitions of each of the variables presented, as well as the year for each pair of country-variable. These sources are the OECD Education at a Glance 2016, OECD Income Inequality Update 2016, Hertz et al. (2007) and Davies et al. (2011)

Table 1: Relevant Statistics

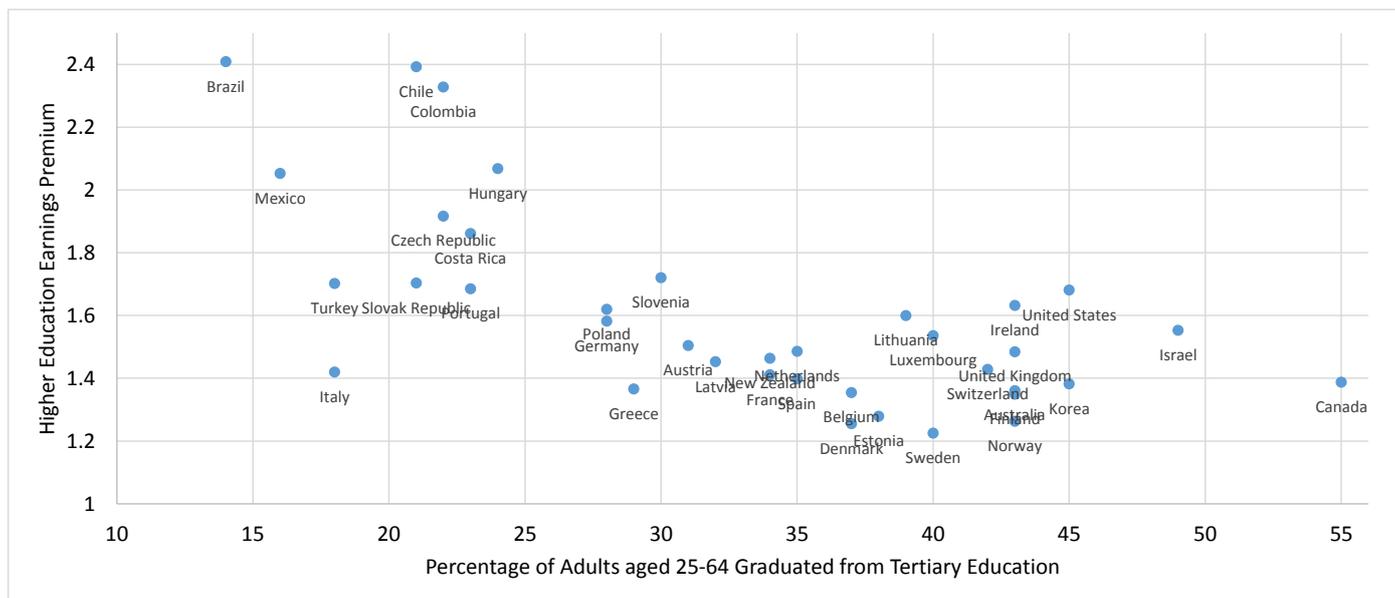
	Chile	USA	Norway	OECD
Household Disposable Income Gini	0.465	0.394	0.252	0.318
Household Wealth Gini	0.777	0.801	0.633	
Public Expenditure on H.E. as % of GDP	1.0%	1.0%	1.5%	1.1%
Private Expenditure on H.E. as % of GDP	1.4%	1.7%	0.1%	0.5%
Adults Graduated from H.E.	21%	45%	43%	42%
H.E. Earnings Premium	2.39	1.68	1.26	1.55
Parent Child Schooling Correlation	0.60	0.46	0.35	
Parent Child Schooling $\beta_s$	0.64	0.46	0.40	

The first two rows are merely motivational as they indicate present distributional outcomes in income and wealth. The third and fourth rows manifest the resemblance of Chile with the U.S. in its high proportion of higher education expenditure that is covered by privates, corroborating Chile's current system as the Anglo-American. This is relevant because higher education expenditures are a significant part of some household's expenditures, and induce precautionary savings if uncertain.

But why is Chile more interesting to study than the U.S. for the question at hand? The first half of the answer is given by the next two rows: it has a small proportion of higher education graduates among 25-64 year-olds, and very high earnings premium (which refers to the times labor earnings is higher for HE graduates than secondary graduates). These two variables suggest that general equilibrium effects might be substantial in Chile for educational policies, i.e. the earnings premium might be reduced in a greater degree. The following chart<sup>11</sup> illustrates the situation of the OECD countries and some of its partners.

<sup>11</sup>Source: Own elaboration based on OECD data.

Figure 1:



The second half of the answer is provided by Hertz et al. (2007) who studied the correlation coefficient of parent and child years of schooling for a number of countries, as well as the regression coefficient of

$$s_1 = \alpha + \beta_s s_0 + \epsilon$$

Where  $s_1$  are the child's years of schooling and  $s_0$  the parents'. Those two measures are the seventh and eight rows of Table 1 respectively. Both evidence significantly larger intergenerational correlation in educational attainment in Chile than its benchmarks. In fact Chile's correlation ranks higher than any country that is not Latin American, a country group that far outranks all others. And this can only be explained through intergenerational links between parent and child of some kind. The links that could take credit for this result are many, but the model of section 4 covers the two most covered by the literature as the best candidates in explaining this stylized fact: inter-vivos transfers and inheritance of cognitive and non-cognitive skills. And such strong intergenerational correlation in education strongly suggests tighter links, or an environment which amplifies their effects. Either way, they make Chile a more interesting country to investigate, because higher importance of inter-vivos transfers in determining the child's education could induce higher precautionary savings.<sup>12</sup>

<sup>12</sup>One may notice that the measures presented cover all levels of schooling, from primary through tertiary, and that the results may not hold when analyzing solely tertiary education, the object of this investigation. Appendix A presents evidence countering this concern. The measures presented here were chosen for their simplicity over those presented in the appendix.

## 3.2 Stylized Facts

This subsection intends to deal specifically with Chilean data. First, savings and wealth accumulation behavior is crucial to the mechanism, and a succinct review of facts is in order. The best recent data is provided by the *Encuesta Financiera de Hogares* (EFH) 2014, a survey intending to characterize household financial balances in detail. First off, 26% of households surveyed declared to have saved the past twelve months, and this figure becomes 17% for low income households, 27% for mid-income, and 45% for high income, suggesting that savings increases with income.<sup>13</sup> This same sharp correlation is also observed when comparing savings and education: 38% of university and 61% of post-graduate households saved the last month, in comparison with 16% and 21% of primary and secondary education ones respectively.<sup>14</sup>

Gallego & Butelmann (2000, 2001) perform a more extensive, though slightly outdated, analysis of savings in Chile, and find the same patterns. They state that savings rate are mostly determined by transitory income, but also by education, permanent income, and the age profile in a way that is consistent with the life cycle theory. Interestingly, education is correlated positively with savings even after controlling for permanent income, suggesting a pure effect from educational attainment. Also, if a wider definition of savings is used and investment in human capital and durable goods expenditures are incorporated, only 27% of total savings falls under the standard definition, 39% corresponds to human capital investment and the rest to durable goods, using 1997 data.

Back to the EFH 2014, our next interest are wealth statistics. The EFH analyzes net wealth (assets minus liabilities) without considering funds from obligatory savings: available net wealth. The distribution is highly skewed, as is expected from a high Gini: The mean wealth is 42 million CLP, and percentiles 25, 50, 75 and 90 are 1, 18, 44 and 98 million CLP respectively.<sup>15</sup> Both wealth mean and median are increasing in household income group, age group, and educational attainment.

Moving on to mainstream educational indicators, a key piece of data in this analysis is through dropout rates. An exact figure is not possible to find because higher edu-

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<sup>13</sup>These figures and the following do not consider obligatory savings: those destined for the Chilean pension system of AFP's.

<sup>14</sup>Educational attainment corresponds to the education attained by the person of reference in the household, which is determined by the Canberra Group standards, and usually results in the household member with the highest income.

<sup>15</sup>The EFH has over-representation of high income groups in its sample in order to better study this group due to its high heterogeneity. This implies that the wealth distribution is not completely representative of the Chilean population.

cation desertion is a complex phenomenon<sup>16</sup>, where a single student may stop studying temporarily and resume in later years, may switch between educational programs, or between educational institutions. Causes of dropping out may be several as well: financial constraints, vocational issues, poor academic performance, and many others. A reasonable figure to follow seems to be the second year institutional retention rate<sup>17</sup>, which was 56,7% for the Chilean cohort entering the system in 2008.<sup>18</sup> This means that of these students, 56,7% remained in the same educational institution at the end of their second year of studies. Some may drop out in the following years, making this an upwards-biased estimation of the long run the retention rate (though Stratton et al. (2008) points out that most of the dropping out occurs within the first two years). But at the same time a student may change the institution but still pursue a degree in higher education, making this a downwards-biased estimation of the system-wide retention rate. The author of this investigation did not find a better estimation of such a rate.

Our final topic is regarding financial constraints for education in Chile: three modern studies address the issue of estimating their existence and relevance for tertiary educational attainment. Alfonso (2009) and Rojas et al. (2016) both use indirect approaches derived from the intuitions of Carneiro & Heckman (2002)<sup>19</sup> and find that financial constraints are not a significant determinant of higher education enrollment. Only Rojas et al. find some evidence suggesting a role for financial constraints in HE graduation, i.e. access to credit is restricted to students once they are attending HE, instead of at the moment of enrollment. Opposite to these studies is Solis (2015), who uses a regression discontinuity study<sup>20</sup> and finds loan access implies an increase of nearly 20 percentage points in enrollment in the first, second and third year of college, representing relative increases of 100%, 200% and 400%, respectively. These increasing figures support Rojas'

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<sup>16</sup>A good analysis is provided by the *Serie Evidencias: Deserción en la Educación Superior en Chile* by the Chilean Ministry of Education in 2012.

<sup>17</sup>A retention rate is the opposite of a dropout rate.

<sup>18</sup>Comisión de Financiamiento para la Educación Superior (2012).

<sup>19</sup>Alfonso (2009) estimates the effect of current income on college enrollment with logistic regressions, controlling for relevant variables (mainly long run variables including measures of permanent income). She argues that the presence of liquidity constraints would imply that current income would play a role in college enrollment. As she finds no such effect, she concludes financial constraints are not significant. Rojas et al. (2016) take a different approach and calculate higher education returns for students who attended HE and those at the margin of attending. The intuition they follow from Carneiro & Heckman (2002) is that if the returns of the latter group are larger than those of the former one we could be in presence of unobservable barriers to higher education access, such as credit constraints. They do not find this for college enrollment. It is the opinion of this thesis' author that their approach is not very trustworthy, as college rates of return are quite difficult to estimate correctly, especially for those at the margin.

<sup>20</sup>This is enabled because the *Crédito con Aval del Estado* and *Fondo de Crédito Solidario* loan programs are only given to students with a national admission test score above a specific cutoff. Solis studies the difference between students directly below and above the cutoff.

finding that credit constraints are relevant for graduation, even if they were not for enrollment.

Thus, the small available literature on this matter is divided, and the authors do not provide criticisms of each other in their works. It is the author's opinion that Solis uses a more rigorous empirical methodology than both other authors, minimizing possible bias and providing a more reliable estimation. He also presents survey answers indicating that a significant number of potential students declare they did not enroll in higher education due to financial constraints. However, it must be noted that formally, this matter is unsettled.

## 4 Model

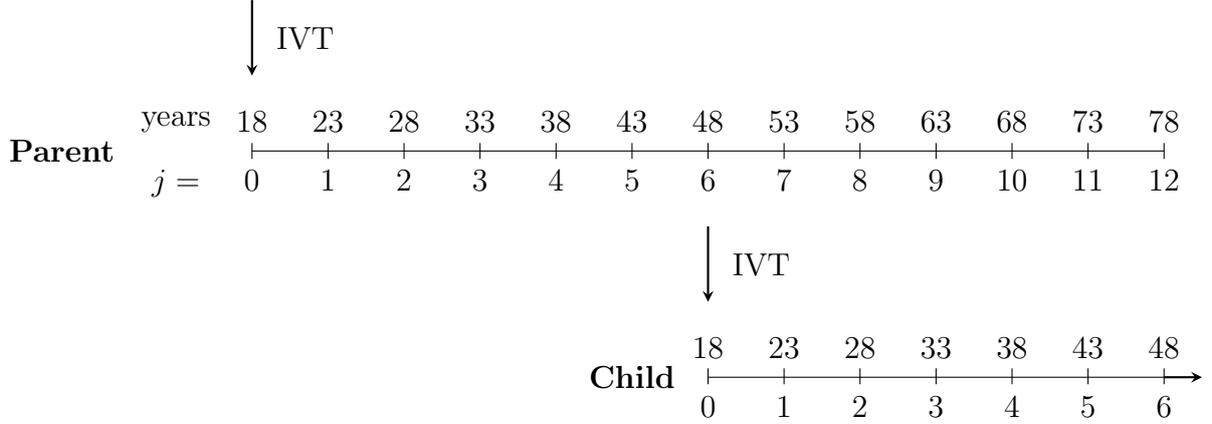
This section builds a model that captures the main economic mechanisms investigated. The structure represents the initial steady state of the economy, and in the final subsection it incorporates a policy reform: universal free higher education financed by graduate taxes.

### 4.1 Preliminaries

Time is discrete and continues forever, but since there are no aggregate shocks and the economy is always described in steady state, time subscripts are omitted. A period in the model corresponds to five years. The economy is populated by 13 overlapping generations, where each generation is a continuum of measure one of individuals (also called agents or households). Each generation is presently in one of the periods  $j \in \{0, 1, \dots, J\}$  of the life cycle. At each date a new cohort of measure one enters the economy, and another one leaves, making the model's age distribution stationary. The first period of life in the model ( $j = 0$ ) corresponds to age 18 and the last one ( $j = J = 12$ ) to age 78, after which agents pass away.

Individuals beginning adult life choose between enrolling in higher education or entering the workforce. Should they opt for education, the entirety of  $j = 0$  is spent studying, and in  $j = 1$  they enter the workforce. All individuals proceed to work the following periods of the life cycle up until  $j^{RET} = 9$ , when they retire and spend the last four periods without labor income. Thus, the three stages of the life cycle are education (which is optional), work and retirement. However,  $j = j^{IVT} = 6$  is arguably the most important period of the life cycle in this model, as parents make an inter-vivos transfer to their children, who

have just started their own life cycle at  $j = 0$ . We illustrate with the following diagram regarding a parent and its child:



A representative firm produces the final good with aggregate capital  $K$  (which depreciates at a rate  $\delta$ ), aggregate human capital  $\mathcal{H}$ , and exogenous and constant total factor productivity  $A$ :

$$Y = AK^\alpha \mathcal{H}^{1-\alpha} \quad (1)$$

Workers are classified as skilled labor if they completed tertiary education, and unskilled if they did not. The former's aggregate labor input is  $H^S$  and the latter's  $H^U$ , and they are aggregated together as imperfect substitutes with shares  $s^S$  and  $s^U$  respectively, with constant elasticity of substitution governed by  $0 < \rho < 1$ :

$$\mathcal{H} = [s^U (H^U)^\rho + s^S (H^S)^\rho]^{1/\rho} \quad (2)$$

Modeling production in this economy according to equations 1 and 2 is fundamental in order to generate the mechanisms studied. Because wages for each kind of labor are equal to marginal productivity of the corresponding type of labor, and because they are imperfect substitutes, an increase in the proportion of skilled labor relative to unskilled will lower skilled wages and raise unskilled wages in general equilibrium. This, in turn, will have implications on income and wealth distributions, as is shown in section 6.

Individual preferences over consumption  $c$  are simple:

$$u(c) = \frac{c^{1-\gamma}}{1-\gamma} \quad (3)$$

Where  $\gamma$  is the relative risk aversion coefficient. This utility refers to a specific age of the individual and time of the model. Individuals discount utility by a factor  $\beta$  for each

period.

Financial markets are incomplete: agents can buy risk-free bonds at the exogenous interest rate, but cannot buy state-contingent insurance against individual labor-income risk. The economy is small and perfectly open in capital markets, therefore aggregate capital need not equal aggregate household assets. Also, households are liquidity constrained: they may not borrow, which means their assets cannot be negative. This liquidity constraint is another fundamental aspect: it means agents are not able to borrow in order to pay for tuition fees. Then, a policy reform implementing free higher education will enable agents that were previously liquidity constrained to study, increasing higher education attainment, the proportion of skilled labor over total, and triggering the general equilibrium effects mentioned above.<sup>21</sup>

The government runs a pension system which pays a benefit  $p$  to retirees, financed by capital, labor and income taxes. This pension is the same for all agents to simplify the model in the retirement period, which is not fundamental for my analysis. These taxes also finance non-valued government consumption  $G$ , which plays no role in this model.

## 4.2 Life Cycle

During the life cycle, agents can be either studying, working, or retired. At the very beginning of an agent's life cycle, ability  $\theta$  is drawn from the discrete set  $\Theta$ . This parameter represents cognitive and non cognitive competence, both innate and acquired through primary and secondary education. In this model, it affects the probability of graduating from higher education, and income. Before being drawn, it follows a probability distribution conditional on the parent's ability, and after drawn it becomes a deterministic state variable for the rest of the agent's life cycle.

Knowing the child's ability, the parent chooses values for education-conditional inter vivos transfers  $\hat{a}$  and  $\tilde{a}$ . The former corresponds to the transfer the child will receive if he chooses to enter higher education, and the latter is conditional on entering the workforce immediately. Taking these conditional transfers and ability  $\theta$  into consideration, agents decide whether to study or work in  $j = 0$ . Thus their value function at this moment is

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<sup>21</sup>Not allowing households to borrow may be a strong assumption in this model. Chilean student aid provides credit and scholarships conditional on academic performance and family socioeconomic background, which could be incorporated in the initial steady state. While this is desirable, it is not incorporated in order to highlight the mechanisms at play. However, student credit is modeled and discussed in subsection 6.4.

the best of the two alternatives:

$$V_0^*(\hat{a}, \tilde{a}, \theta) = \max\{V_0^H(\hat{a}, \theta), \mathbb{E}_z[V_0^U(\tilde{a}, \theta, z_0)]\} \quad (4)$$

$$z_0 \sim \Gamma_z^S(z_0)$$

Where  $V_0^*$  is the value before taking the decision,  $V_0^H$  is the value obtained if the agent decides to enter higher education, and  $\mathbb{E}_z[V_0^U]$  is the expected value of deciding to work as unskilled labor. It is not deterministic because income depends on the initial productivity shock,  $z_0$ , which is not known to the agent until after the decision to work is made. The probability distribution of  $z_0$  is the stationary distribution of shocks in the population,  $\Gamma_z^S$ , which will be further explained in the working stage. It must also be noted that parents are aware of this value function and the decision the child will take given any set of  $\{\hat{a}, \tilde{a}\}$ , and can influence the education decision by choosing the conditional transfers. This will be explained further in subsection 4.3, for now we must explain the problem faced by the higher education student.

#### 4.2.1 Education

Should the agent decide to study, he will face the following value function:

$$V_0^H(\hat{a}, \theta) = \max_{c_0, a_1} u(c_0) + \beta [\kappa(\theta)\mathbb{E}_z[V_1^S(a_1, \theta, z_1)] + (1 - \kappa(\theta))\mathbb{E}_z[V_1^U(a_1, \theta, z_1)]] \quad (5)$$

Subject to

$$c_0(1 + \tau_c) + a_1 + \phi = \hat{a}$$

$$c_0, a_1 \geq 0$$

$$z_1 \sim \Gamma_z^S(z_1)$$

As can be noted, the student's decision is only how much to consume and how much to save in assets for the next period,  $a_1$ . Note that these assets for next period cannot be negative: the student may not borrow and thus faces liquidity constraints in face of the educational expenses: the tuition fee for higher education  $\phi$ .<sup>22</sup> These constraints will

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<sup>22</sup>Note that tuition fees are the marginal cost of higher education. They are considered constant, and educational supply is infinitely elastic (anyone who decides to study can, there is no selection mechanism such as the best scores of an admission test). This is only reasonable if we are studying long-term effects, which is the case of this investigation. In the long term, if educational demand increases, actual institutions might grow and new institutions might sprout. And comparing two overlapping-generation steady states means that after the reform, all generations must be different from those present in the initial steady states, therefore these changes could only occur after many decades. That is why this is a long term model that is not valid for analyzing short term effects of educational policies, but provides the general direction and destination of the variables studied.

be relevant if the transfer received from parents  $\hat{a}$  is not large enough. Finally  $\tau_c$  is the consumption tax rate.

Present value  $V_0^H$  includes utility from present consumption and the expected of value of next period, discounted by  $\beta$ . Next period value is uncertain for two reasons. First, because the initial productivity shock  $z_1$  is uncertain, in the same fashion as for agents who decided to work. Second, because students face a probability of graduating that is increasing on their ability,  $\kappa(\theta)$ . If the student graduates, he becomes skilled labor for the duration of his life cycle. But the student may also drop out<sup>23</sup> with probability  $1 - \kappa(\theta)$ , and end up as unskilled labor. Intuitively, agents may choose to enter the workforce immediately if they have a low probability of graduating, even if income is higher as skilled labor, because the opportunity cost of studying includes the income which would be earned in the case of working in  $j = 0$ , as shown below.

#### 4.2.2 Work

If the agent in  $j = 0$  decides to work, he will face a different problem:

$$V_0^U(\tilde{a}, \theta, z_0) = \max_{c_0, a_1} u(c_0) + \beta \mathbb{E}_z[V_1^U(a_1, \theta, z_1)] \quad (6)$$

Subject to

$$\begin{aligned} c_0(1 + \tau_c) + a_1 &= (1 - \tau_y)y_0 + \tilde{a} \\ y_0 &= w^U \varepsilon_0^U(\theta, z_0) \\ c_0, a_1 &\geq 0 \\ z_1 &\sim \Gamma_z(z_1|z_0) \end{aligned}$$

In this case, the agent has labor income  $y_0$ , which is determined by the efficiency units  $\varepsilon$  he provides and the wage per efficiency unit of unskilled labor  $w^U$ . These units depend on four characteristics throughout the life cycle: age, ability, the idiosyncratic productivity shock, and education.  $\varepsilon$  is increasing with age at decreasing rates, in order to generate a standard hump-shaped pattern of life cycle labor income. Efficiency units are also increasing with ability, intending to reflect a higher productivity, and providing a determinant of permanent income.  $z_j$  affects the agent's problems through a transitory increase or decrease in efficiency units and thus labor income. And finally, education is important because age and ability profiles of efficiency units are different for unskilled and skilled labor.<sup>24</sup>

<sup>23</sup>All dropouts are involuntary in this model.

<sup>24</sup>Specifically, HE graduates have a steeper age profile, and ability is a more important determinant

$z_1 \sim \Gamma_z(z_1|z_0)$  means that the probability distribution for next period's idiosyncratic productivity shock is now conditional on the present shock. In particular, there is persistence of shocks through time. The values of  $z_j$  are assumed to belong to a discrete set  $\mathcal{Z}$ , and they follow a finite markovian process. The conditional probabilities are modeled as a transition matrix which is reviewed in detail in section 5. The stationary distribution of shocks  $\Gamma_z^S$  mentioned previously can be obtained from the stationary distribution of the transition matrix.

After the period  $j = 0$ , all agents work from  $j = 1$  through  $j = 8$ . Allowing for some exceptions detailed below, the problem the agents face during this stage can be generally represented for period  $j \in \{1, 2, \dots, 8\}$  and educational attainment  $e = \{U, S\}$  as follows:

$$V_j^e(a_j, \theta, z_j) = \max_{c_j, a_{j+1}} u(c_j) + \beta \mathbb{E}_z[V_{j+1}^e(a_{j+1}, \theta, z_{j+1})] \quad (7)$$

Subject to

$$\begin{aligned} c_j(1 + \tau_c) + a_{j+1} &= (1 - \tau_y)y_j + a_j(1 + r(1 - \tau_a)) \\ y_j &= w^e \varepsilon_j^e(\theta, z_j) \\ c_j, a_{j+1} &\geq 0 \\ z_{j+1} &\sim \Gamma_z(z_{j+1}|z_j) \end{aligned}$$

Where  $r$  is the interest rate paid by assets, and  $\tau_a$  is a tax on the gains by investment in assets.

There are three exceptions to this case. First, in  $j = j^{IVT} = 6$  the agents make an inter-vivos transfer to their children, and this decision makes for a different problem. The second exception is the period before IVT's,  $j = j^{IVT} - 1$ , in which the parent faces the child's ability as one of next period's state variables. Both these cases will be covered in 4.3. The third exception is the period before retiring,  $j = j^{RET} - 1$ , in which the constraints are the same as shown above but the value function becomes:

$$V_8^e(a_8, \theta, z_8) = \max_{c_8, a_9} u(c_8) + \beta V_9^R(a_9) \quad (8)$$

Reflecting the agent's retirement the next period:  $V_j^R(a_j)$  is the value function of the retiree and will be explained below.

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of income. This is explained in detail in section 5.

### 4.2.3 Retirement

During the retirement stage from  $j = 9$  to  $j = 12$ , agents do not work or study. They receive pension payments  $p$  and may not borrow from the financial market. Including all of this, the retiree's value function is as follows:

$$V_j^R(a_j) = \max_{c_j, a_{j+1}} u(c_j) + \beta V_{j+1}^R(a_{j+1}) \quad (9)$$

Subject to

$$\begin{aligned} c_j(1 + \tau_c) + a_{j+1} &= p + a_j(1 + r(1 - \tau_a)) \\ c_j, a_{j+1} &\geq 0 \end{aligned}$$

And  $V_{13}^R = 0$ . This retirement stage is firstly important to incorporate for the model to produce a more realistic wealth distribution and ease the model's calibration. But also because it enables changes in income to be reflected in changes in assets. High earners will want to smooth their consumption between their working and retirement stages, and will tend to save. This is the reason why changes in the wealth distribution will mimic some of the changes in the income distribution in the results.

## 4.3 Intergenerational Linkages

The first link between parent and child in this model is the intergenerational correlation in ability. This is better explained by discussing the agent's problem in  $j = 5$ :

$$V_5^e(a_5, \theta, z_5) = \max_{c_5, a_6} u(c_5) + \beta \mathbb{E}_{z, \theta} [V_6^e(a_6, \theta, \theta_C, z_6)] \quad (10)$$

Subject to

$$\begin{aligned} c_5(1 + \tau_c) + a_6 &= (1 - \tau_y)y_5 + a_5(1 + r(1 - \tau_a)) \\ y_5 &= w^e \varepsilon_5^e(\theta, z_5) \\ c_5, a_6 &\geq 0 \\ z_6 &\sim \Gamma_z(z_6|z_5) \\ \theta_C &\sim \Gamma_\theta(\theta_C|\theta) \end{aligned}$$

Where it must be noted that the child's ability  $\theta_C$  is a relevant state variable for next period, and it is uncertain: next period's expected value concerns probabilities for both  $z_6$  and  $\theta_C$ . The probability distribution for the latter is given by  $\Gamma_\theta$ , and is conditional on the parent's ability: high ability parents are more likely to have high ability children.

Since  $\theta$  comes from a discrete set of values, this intergenerational correlation is achieved through a transition matrix, which is detailed in section 5.

Uncertainty about children's ability is fundamental for one of the mechanisms studied: precautionary savings due to uncertain education expenses. In order to discuss this, we can analyze the Euler equation governing the consumption/saving decision in this period:

$$u'(c_5) \geq \beta(1 + r(1 - \tau_a))\mathbb{E}_{z,\theta}[u'(c_6)] \quad (11)$$

Where  $u'(c_5)$  is equal to the right hand side if  $a_6 > 0$  and strictly higher if  $a_6 = 0$ . Imagine, as an example, if for some low values of  $\theta_C$  the parent does not transfer the cost of education  $\phi$ , and for some high values of  $\theta_C$  he does. This implies that  $c_6$  will have some volatility due to education expenditures: it will be higher if the parent does not transfer  $\phi$  and instead consumes those resources, and lower if the parent does transfer. Because  $u(c)$  is a concave function, by the Jensen Inequality this volatility in consumption raises the term  $\mathbb{E}_{z,\theta}[u'(c_6)]$ .<sup>25</sup> The Euler equation implies a rise (or no effect depending on liquidity constraints) of  $u'(c_5)$ , which can only be achieved by reducing consumption and raising  $a_6$ : precautionary savings. This will not occur if higher education is free. If  $\phi = 0$ , then a high or low draw of  $\theta_C$  will not imply higher or lower consumption due to educational expenditures, which will always be zero. Then, if the policy reform is implemented, we should observe a fall in assets corresponding to the lower precautionary savings.

The second intergenerational link consists of monetary transfers from parent to child: inter-vivos transfers. These are determined in period  $j = 6$ :

$$V_6^e(a_6, \theta, \theta_C, z_6) = \max_{c_6, a_7, \hat{a}, \tilde{a}} u(c_6) + \beta\mathbb{E}_z[V_7^e(a_7, \theta, z_7)] + \omega V_0^*(\hat{a}, \tilde{a}, \theta_C) + \xi \cdot \mathbb{H}(\hat{a}, \tilde{a}, \theta_C) \quad (12)$$

Subject to

$$\begin{aligned} c_6(1 + \tau_c) + a_7 + \mathbf{a} &= (1 - \tau_y)y_6 + a_6(1 + r(1 - \tau_a)) \\ y_6 &= w^e \varepsilon_6^e(\theta, z_6) \\ c_6, \hat{a}, \tilde{a}, a_7 &\geq 0 \\ z_7 &\sim \Gamma_z(z_7|z_6) \end{aligned}$$

After the ability of the child has been determined, it becomes a state variable relevant for the parent's decision. The amount of the inter-vivos transfer becomes a control variable,

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<sup>25</sup>This is because marginal utility increases by more in the states where  $c_6$  is lower than the decrease in the states where  $c_6$  is higher, thanks to decreasing marginal utility.

where  $\mathbf{a}$  corresponds to  $\hat{a}$  if the child is induced to enroll in higher education, and  $\tilde{a}$  if not. Note that the parent knows all the information necessary ( $\theta_C$ ) to be able to discern perfectly which amounts of  $\hat{a}$  and  $\tilde{a}$  will induce which decision on part of its offspring. And this is expressed through  $\mathbb{H}$ , which is an education decision indicator that takes a value of 1 when the child decides to attend education, and 0 when he decides to work immediately. Formally,

$$\begin{aligned} \text{if } V_0^H(\hat{a}, \theta_C) > \mathbb{E}_z[V_0^U(\tilde{a}, \theta_C, z_0)] &\Rightarrow \mathbf{a} = \hat{a} \quad \& \quad \mathbb{H} = 1 \\ \text{if } V_0^H(\hat{a}, \theta_C) < \mathbb{E}_z[V_0^U(\tilde{a}, \theta_C, z_0)] &\Rightarrow \mathbf{a} = \tilde{a} \quad \& \quad \mathbb{H} = 0 \end{aligned}$$

The parent cares about its child through two relevant channels.  $V_0^*(\hat{a}, \tilde{a}, \theta_C)$  is the value of the child which depends on the transfers, and  $\omega$  is a parameter reflecting the parent's altruistic desire for the child's well being, the first channel. The second one is the paternalistic desire for the child to attend higher education, quantified in  $\xi$ . This parameter is added to parental utility if the indicator  $\mathbb{H}$  becomes one, that is if the child decides to get educated. Abbott et al. (2013) argue that this parameter is key to producing realistic results in terms of higher education student characteristics, namely the high presence of low ability-high wealth students.

## 4.4 Stationary Equilibrium

Stationarity implies that we study an equilibrium such that the cross-sectional allocation of state variables for any given cohort of age  $j$  is invariant over the sequence of time periods  $t \in \{t_0, t_1, \dots\}$ . In the following definition, it is useful to consider  $s_j \in S_j$  as the vector of state variables for an individual of age  $j$ .

Formally, a **stationary recursive competitive equilibrium** for this economy is a collection of: (i) decision rules for tertiary education  $\mathbb{H}(s_0)$ , consumption  $c_j(s_j)$ , wealth  $a_{j+1}(s_j)$  and inter-vivos transfers  $\hat{a}(s_6)$  &  $\tilde{a}(s_6)$ ; (ii) value functions  $V_0^H(s_0)$ ,  $V_j^U(s_j)$ ,  $V_j^S(s_j)$ ,  $V_j^R(s_j)$ ; (iii) aggregate capital and labor inputs  $K$ ,  $H^U$ ,  $H^S$ ; (iv) prices  $w^U$  and  $w^S$  such that:

1. Given  $w^U$  and  $w^S$ , the decision rules  $\mathbb{H}(s_0)$ ,  $c_j(s_j)$ ,  $a_{j+1}(s_j)$ ,  $\hat{a}(s_6)$  &  $\tilde{a}(s_6)$  solve the respective household problems, and  $V_0^H(s_0)$ ,  $V_j^U(s_j)$ ,  $V_j^S(s_j)$ ,  $V_j^R(s_j)$  are the associated value functions.
2. The representative firm optimally chooses factors of productions, and input prices

equate their marginal products,

$$r + \delta = F_K(K, \mathcal{H}) \quad (13)$$

$$w^U = F_{H^U}(K, \mathcal{H}) \quad (14)$$

$$w^S = F_{H^S}(K, \mathcal{H}) \quad (15)$$

3. The labor market clears for each kind of human capital. That is, considering a continuum of measure 1 of individuals  $i$ , for a given cohort first define:

$$\bar{\mathbb{H}} = \int \mathbb{H}_i di \quad (16)$$

$$\bar{\kappa} = \int_{\mathbb{H}=1} \kappa(\theta_i) di \quad (17)$$

$$\bar{\mathbb{D}} = 1 - \bar{\kappa} \quad (18)$$

Where  $\bar{\mathbb{H}}$  is the HE enrollment rate of the population, an average of those for whom  $\mathbb{H} = 1$ . Note that in steady state, this value is the same for all cohorts.  $\bar{\kappa}$  is the graduation rate from higher education, note that is is calculated as the average graduation probability only over those who enrolled. Finally,  $\bar{\mathbb{D}}$  is the dropout rate, which is just the opposite of the graduation rate.

Then, clearing of labor markets implies:

$$H^U = (1 - \bar{\mathbb{H}}) \int_{e=U, j=0} \varepsilon_i di + (1 - \bar{\mathbb{H}} + \bar{\mathbb{H}} \bar{\mathbb{D}}) \sum_{j=1}^8 \int_{e=U} \varepsilon_{ij} di \quad (19)$$

$$H^S = \bar{\mathbb{H}} \bar{\kappa} \sum_{j=1}^8 \int_{e=S} \varepsilon_{ij} di \quad (20)$$

Where it must be noted that unskilled labor consists of those who entered the workforce in  $j = 0$  which are a proportion  $1 - \bar{\mathbb{H}}$  of the population, and the dropouts who represent  $\bar{\mathbb{H}} \bar{\mathbb{D}}$ . Skilled labor consists only of those who entered and graduated, a proportion  $\bar{\mathbb{H}} \bar{\kappa}$ .

4. The government meets the budget constraint:

$$\sum_{j=9}^{12} p + G = \tau_c \sum_{j=0}^{12} \int c_{ij} di + \tau_y (w^U H^U + w^S H^S) + \tau_a r \sum_{j=1}^{12} \int a_{ij} di \quad (21)$$

We can elaborate on equations 14 and 15 to get some insight on general equilibrium

adjustment of wages:

$$w^U = AK^\alpha(1 - \alpha)\mathcal{H}^{\frac{1-\alpha-\rho}{\rho}}s^U(H^U)^{\rho-1} \quad (22)$$

$$w^S = AK^\alpha(1 - \alpha)\mathcal{H}^{\frac{1-\alpha-\rho}{\rho}}s^S(H^S)^{\rho-1} \quad (23)$$

$$\frac{w^S}{w^U} = \frac{S^S}{S^U} \left( \frac{H^U}{H^S} \right)^{1-\rho} \quad (24)$$

From equation 24 and recalling that  $\rho < 1$  we can observe that an increase in the provision of skilled labor coupled with a decrease in the provision of the unskilled kind will decrease the wage premium per efficiency unit. Equations 22 and 23 suggest that the changes will not only be relative, but also  $w^S$  will actually fall and  $w^U$  rise. Since skilled agents are higher earners than unskilled, this will probably reduce inequality in income, and possibly in wealth as well.<sup>26</sup>

Finally, note that the goods and capital markets need not clear, since this is a small open economy.

## 4.5 Policy Reform

The policy reform to be evaluated in this investigation is the implementation of free higher education, completely financed with graduate taxes. This can be modeled through very simple changes that have important implications. First, the cost of education  $\phi$  is now zero. Agents who choose education will have the budget constraint loosening to  $c_0(1 + \tau_c) + a_1 = \hat{a}$ . For the agents who manage to graduate and become skilled labor, in their working stages they will also have to pay the graduate tax  $\tau_g$ , and thus their budget constraint will be:

$$c_j(1 + \tau_c) + a_{j+1} = (1 - \tau_g)(1 - \tau_y)y_j + a_j(1 + r(1 - \tau_a)) \quad (25)$$

$$y_j = w^S \varepsilon_j^S(\theta, z_j)$$

No other part of the agent's life cycle problems will change: unskilled workers will not pay the graduate tax, and inter-vivos transfers will continue to occur due to  $\omega$  and  $\xi$ . From this simple context we can explain another mechanism which can change the wealth distribution. Note that previous to the policy reform, educational expenses were covered in period  $j = j^{IVT}$  of the life cycle, some time after the agent started working,<sup>27</sup> in the

<sup>26</sup>Since agents have a period of retirement, higher income translates into higher asset holdings in order to smooth intertemporal consumption with respect to this period. If high-earner's income is reduced, their assets will be reduced, lowering the wealth gini.

<sup>27</sup> $j^{IVT} = 6$  is meant to be interpreted as 48 years of age.

form of (a part of)  $\hat{a}$ . However, now they are paid throughout the whole life cycle of skilled agents, in the form of  $\tau_g$ . This means educational expenses have been spread out over the life cycle, for which reason the agent does not need to save previous to  $j^{IVT}$  in order to smooth consumption, because income net of educational expenses is now more even over the life cycle.

Moving on, the amount of the graduate tax is that which balances the budget constraint for this policy reform in itself. That is, in equilibrium, it must hold that:

$$\phi \bar{\mathbb{H}} = \tau_g(1 - \tau_y)w^S H^S \quad (26)$$

The left hand side measures the amount of expenses, given by the individual tuition fee which must be covered for the proportion of the population that enrolls.<sup>28</sup> It must be noted that  $\bar{\mathbb{H}}$  can (and will, as is hypothesized) change after the policy reform, relative to the initial steady state. The right hand side is the income regarding the policy budget constraint, given by the tax rate  $\tau_g$  and the tax base which is skilled disposable income,  $(1 - \tau_y)w^S H^S$ . Using the labor market clearing in the budget constraint and rearranging may provide further insight:

$$\bar{\mathbb{H}} \phi = \bar{\mathbb{H}} \bar{\kappa} \sum_{j=1}^8 \int_{e=S} \tau_g(1 - \tau_y)w^S \varepsilon_{ij} di \quad (27)$$

Leaving liquidity constraints aside, the reform's direct benefit for agents ( $\phi = 0$ ) is given to a proportion  $\bar{\mathbb{H}}$  of the population. On the other hand, the direct cost of the reform (graduate taxes) is borne by a proportion  $\bar{\mathbb{H}} \bar{\kappa}$  of the population, which is lower. This is because dropouts do not pay for the free education they received, only those who graduated do. This is a reason to wonder whether the graduate tax may discourage enrollment and lower attainment, because if dropout rates are high the rate of  $\tau_g$  might be substantial. This is another of the mechanisms at play, and might be further understood by clearing  $\tau_g$  from the previous equation. For the sake of parsimony, define:

$$\bar{\varepsilon}_S = \sum_{j=1}^8 \int_{e=S} \varepsilon_{ij} di \quad (28)$$

Then, rearranging 27 and using 18 yields:

$$\tau_g = \frac{1}{1 - \mathbb{D}} \left( \frac{\phi}{(1 - \tau_y)w^S \bar{\varepsilon}_S} \right) \quad (29)$$

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<sup>28</sup>Note that we assume education costs do not change with the policy reform for simplicity.

From where it is clear that, *ceteris paribus*, the graduate tax rate  $\tau_g$  is increasing on the dropout rate. If the policy reform increases the amount of dropouts, the graduate rate might provide a stronger disincentive to enrollment, reinforcing the mechanism discussed above. This competes directly with another mechanism: the lifting of education liquidity constraints that the reform provides, which encourages enrollment and increases attainment. Having built the model and explained the mechanisms at work in the hypothesis, the next two sections address the computational exercise carried out.

## 5 Calibration

The intention of this investigation is to simulate a policy reform and produce an estimation of its effects on the wealth distribution and various moments of interest. The estimation of the initial steady state (before the reform) must resemble the economy investigated in the moments of interest in order for the simulation to be valid. Therefore, our strategy consists of first calibrating the model so that the initial steady state resembles the Chilean economy and higher education system. Then, with the parameter values resulting from the previous calibration, we calculate a new steady state that incorporates the policy reform mentioned in subsection 4.5. The differences in the moments of interest can be interpreted as an estimation of the long-run effects of the policy.

Our general calibration strategy consists of obtaining parameters from three different sources in the following priority: Chilean data or literature, Abbott et al. (2013), and finally if those are not possible or reasonable, we calibrate the parameters to match a set of target moments. The result is 7 parameters obtained from Chilean data, 10 from the mentioned paper, and 6 calibrated. Also, the author decided that the unit of measure of individual income, consumption, assets, education costs and pensions will be million 2011 CLP. This is done to ease interpretation of model outputs.

Regarding Chilean data: annual depreciation of capital is drawn from the Penn World Tables, taking an average of the years 2000-2015, resulting in an annual estimate of 4.11%. A robustness check of the results was carried out with higher depreciation as well, in appendix C. The international exogenous interest rate comes from the same average of years of the real interest rate presented by the World Bank data,<sup>29</sup> which is 3.08%.<sup>30</sup> In

<sup>29</sup>This is presented as the Chilean real interest rate. However, since Chile is a small open economy, it should be interpreted as the international real interest rate plus a risk premium,  $r = r^* + \rho$ . Since neither of these two elements is assumed to change during the steady states calculated, this notation is omitted for simplicity and  $r$  is used as the prevailing real interest rate.

<sup>30</sup>The World Bank defines it as *the lending interest rate adjusted for inflation as measured by the GDP deflator*. Also, the lending interest rate is defined by the IMF (the data source for the World Bank) as

a five year period,  $\delta$  and  $r$  end up as 18.93% and 16.38% respectively. Three robustness checks were carried out in appendix C regarding the interest rate: lower interest rate, a higher rate, and a closed economy in which the interest rate is determined endogenously through the clearing of the asset market.

The cost of education  $\phi$  is chosen to match the average direct private costs faced by Chilean students who would enter and complete tertiary education in 2011 which amount to 13,259,000 CLP.<sup>31</sup> In million 2011 CLP, this implies  $\phi = 13.259$ . From the Chilean *Superintendencia de Pensiones*, the average pension in January 2011 was around 175,000 CLP, which translates into 10.515 million CLP in five years, the value of  $p$ . Finally, consumption taxes  $\tau_c = 19\%$  are matched to the Chilean IVA tax, and labor income and capital income taxes are assumed to be  $\tau_a = \tau_y = 25\%$  following Chumacero & Fuentes (2006).

Several parameters of the model are taken directly from Abbott et al.: the CES parameter governing the elasticity of substitution between skilled and unskilled human capital,  $\rho$ , is 0.7. They estimated this parameter from the Current Population Survey 1968-2001. The share of skilled labor in the human capital aggregator is  $s^S = 0.46$ , and thus the unskilled share is  $s^U = 0.54$ , as both must sum one.<sup>32</sup> Altruism  $\omega = 0.27$  is an average of their altruism towards sons and altruism towards daughters, 0.29 and 0.25 respectively. They calibrated this parameter using the simulated method of moments (SMM). The share of capital in the production function  $\alpha$  is 0.33,<sup>33</sup> the utility function CRRA parameter  $\gamma = 2$  and the time discount factor  $\beta$  is  $0.944^{5/2} = 0.8658$ , taking care of their two year periods versus this model's five year periods. They choose this value to replicate an annual capital/product ratio of 4. In any case, an alternative value for  $\beta$  is provided as a robustness exercise in appendix C using a deterministic euler equation.

Regarding efficiency units, recall that they depend on education, age, ability and a stochastic idiosyncratic productivity shock. They depend in the following fashion:

$$\ln(\varepsilon) = f^e(j) + \lambda^e\theta + z_j \quad (30)$$

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*the weighted average rate charged by other depository corporations on 30- to 89-day loans in national currency.*

<sup>31</sup>Education at a Glance 2016, OECD.

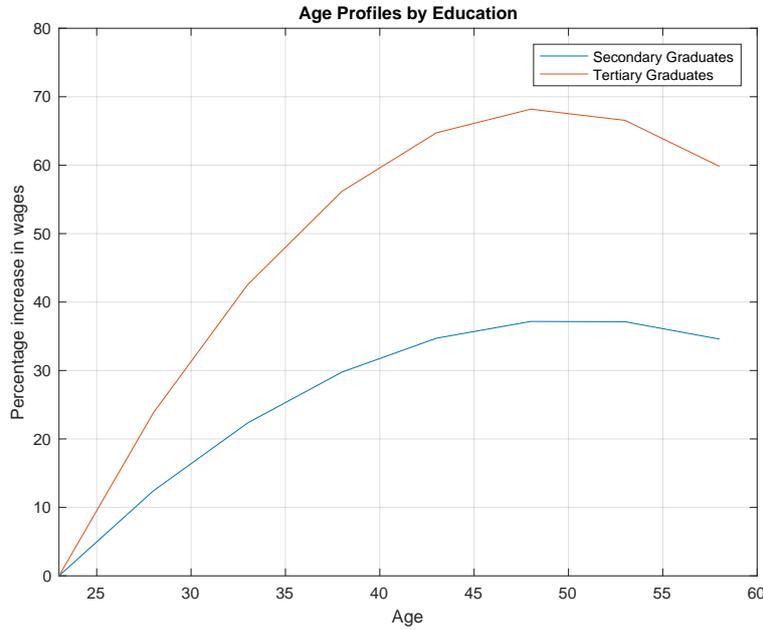
<sup>32</sup>Abbott et al. present three types of labor: high school dropouts, high school graduates, and college graduates. The share of college graduates in their human capital aggregator is 0.46, but the share of high school graduates is 0.38, because the share of high school dropouts is 0.16. Since the model in this thesis does not include high school dropouts, their share of human capital from Abbott et al. is considered to be part of the high school graduates share in this work's model, which corresponds to unskilled labor.

<sup>33</sup>There is a robustness check for a higher value in appendix C

Where  $f^e(j)$  is the age profile which depends on education,  $\lambda^e$  is an ability gradient for each education group, and  $z_j$  is the productivity shock.

The age profile is taken from Abbott et al., and not from Chilean data because said authors differentiate between secondary graduates and tertiary graduates, which have different slopes for their life cycle incomes. Taking an average between males and females, the age polynomial coefficient from Abbot et al.<sup>34</sup> produce the following age profiles:

Figure 2:



Where the y axis indicates the percentage increase in efficiency units relative to period  $j = 1$ . The timeline presented in section 4.1 relates ages to periods in the model. Note that the slope between ages is important, not so the level of efficiency units, because the wages per efficiency unit are determined in general equilibrium and thus compensate if one level of education yields more efficiency units on average than the other.

The purpose of the ability gradient  $\lambda^e$  is to represent a higher profitability of education for high ability students than for low ability students, in line with evidence. Thus,  $\lambda^U = 0.5585$  and  $\lambda^S = 0.7815$ , again an average presented by Abbott et al. for male and female values.  $\theta$  may take five values, each corresponding to an ability quintile in the population. In order to provide these values, we assume that in the population  $\theta \sim N(0, \sigma_\theta)$ ,

<sup>34</sup>They regress log hourly wages on age and age squared, and present the coefficients.

where  $\sigma_\theta$ ) is calibrated to match targets. The five values correspond to percentiles 10, 30, 50, 70 and 90 of said distribution, each representing the corresponding quintile around it. This yields the following ability-efficiency profiles:<sup>35</sup>

$$\lambda^U \theta \in \left\{ \begin{array}{ccccc} -0.859 & -0.352 & 0 & 0.352 & 0.859 \end{array} \right\}$$

$$\lambda^S \theta \in \left\{ \begin{array}{ccccc} -1.202 & -0.492 & 0 & 0.492 & 1.202 \end{array} \right\}$$

For a given individual, the shock is assumed to behave as an AR(1) process, that is  $z_j = \varrho z_{j-1} + \eta_j$ , where  $\eta_j \sim N(0, \sigma_z)$ . The parameter  $\varrho$  is obtained from Abbott et al.: It is the average persistence of male and female, HS graduates and college graduates, translated into a five year period, which yields  $\varrho = 0.8303$ . On the other hand,  $\sigma_z$  is calibrated to match targets. Then, a discrete markovian process is built using the Tauchen (1986) method, which may map the AR(1) shock process with parameters  $\rho$  and  $\sigma_z$  into three possible values  $\mathcal{Z}$  with a 3x3 transition matrix  $\Pi_z$ . The resulting values are:

$$\mathcal{Z} = \left\{ \begin{array}{ccc} -0.675 & 0 & 0.675 \end{array} \right\}$$

While the transition matrix is

$$\Pi_z = \begin{pmatrix} 0.813 & 0.089 & 0.000 \\ 0.187 & 0.822 & 0.187 \\ 0.000 & 0.089 & 0.813 \end{pmatrix}$$

Where element  $(i, j)$  represents the probability of drawing shock  $j$  given a previous shock  $i$ . This is all done in order to give a discrete functional form to the distribution of shocks in the model,  $z_{j+1} \sim \Gamma(z_{j+1}, z_j)$ , which is a relevant condition for the working agent's value function and is the reason why  $z_j$  is a state variable.

There is another transition matrix: the intergenerational transmission of ability also follows a conditional distribution given by  $\theta_C \sim \Gamma_\theta(\theta_C|\theta)$  from the agent's problem in  $j = 5$ . The transition matrix between quintiles of ability (the five possible values for  $\theta$ ) is taken directly from Abbott et al., due to the high complexity of reproducing it with

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<sup>35</sup>As with age, one must remember that wages per efficiency unit are determined in general equilibrium. If low ability skilled individuals achieve less efficiency units than unskilled individuals, that does not necessarily mean that their income will be lower (*ceteris paribus*), as  $w^S$  may be higher than  $w^U$ . What is important, is that high ability individuals will find it more convenient to enter higher education than their low ability peers, due to a steeper ability-efficiency profile.

Chilean data. We present the matrix:

$$\Pi_{\theta} = \begin{pmatrix} 0.455 & 0.238 & 0.197 & 0.065 & 0.047 \\ 0.258 & 0.242 & 0.242 & 0.157 & 0.110 \\ 0.160 & 0.223 & 0.271 & 0.190 & 0.157 \\ 0.114 & 0.171 & 0.257 & 0.209 & 0.249 \\ 0.072 & 0.076 & 0.195 & 0.242 & 0.415 \end{pmatrix}$$

Where element  $(i, j)$  represents the chance of a child of being in ability quintile  $i$  given a parent in quintile  $j$ . It may be noted that there is high mobility along the middle quintiles, but less to at the bottom and top.

Also, graduation probabilities  $\kappa(\theta)$  for each of the five ability quintiles are needed. They are drawn from the percentiles 10, 30, 50, 70 and 90 of a normal distribution with mean  $\mu_{\kappa}$  and standard deviation  $\sigma_{\kappa}$ , where both parameters are calibrated to match targets.<sup>36</sup> The resulting graduation probabilities, increasing in ability quintiles, are:

$$\kappa(\theta) \in \left\{ 0.019 \quad 0.291 \quad 0.48 \quad 0.669 \quad 0.941 \right\}$$

And finally, paternalism  $\xi$  and aggregate total factor productivity  $A$  are calibrated to match targets as well. The methodology used to estimate the model's steady state general equilibrium is detailed in appendix B. The parameter values, calibration targets and the achieved results in the model's equilibrium are presented in the following table:

Table 2: Calibration

Parameter	Value		Moment	Model	Target
$A$	16		<b>HE Private Expenditure</b>	1.48%	1.4%
$\xi$	0.1		<b>HE Attainment</b>	21.8%	21%
$\mu_{\kappa}$	48%	$\Rightarrow$	<b>HE Dropout Rate</b>	42.1%	43.3%
$\sigma_{\kappa}$	36%		<b>HE Earnings Premium</b>	2.33	2.39
$\sigma_z$	0.45		<b>Income Gini</b>	0.453	0.465
$\sigma_{\theta}$	1.2		<b>Wealth Gini</b>	0.737	0.777

All targets come from the values presented in section 3. Higher education private expenditure is measured as % of GDP, and it ensures that the tuition fee  $\phi$  is not too high or

<sup>36</sup>Special care is taken so that all values are higher than 0 and lower than 1, as they are probabilities.

low relative to the rest of the economy.<sup>37</sup> HE attainment measures the percentage of the population aged 25-64 that graduated from higher education. The target dropout rate is simply the opposite of the second year institutional retention rate, for the reasons argued in said section. The earnings premium corresponds to average earnings of HE graduates relative to average earnings of non graduates. The income gini considers after tax income and the wealth gini is measured through asset holdings.

## 6 Estimation Results

This section details the differences between the wealth distribution before and after the policy reform. In order to disentangle the mechanisms at work, several moments of interest are analyzed in these two steady states in 6.1. Then, 4 other equilibria are calculated, each one intending to shed some light on the effect of some particular mechanism.

As a summary of the mechanisms discussed in section 4, recall that:

- Due to reduced uncertainty about educational expenses, we expect aggregate assets to fall.
- Another reason why assets might fall is the different timing of education expenditure.
- Liquidity constraints are loosened after the policy reform, which might drive educational attainment upwards.
- Graduate taxes might provide a disincentive to educational attainment due to high dropout rates.
- If educational attainment increases, we expect the skilled wages to fall and unskilled wages to rise in general equilibrium, which would lower income and wealth gini.

Without further ado, we present the results:

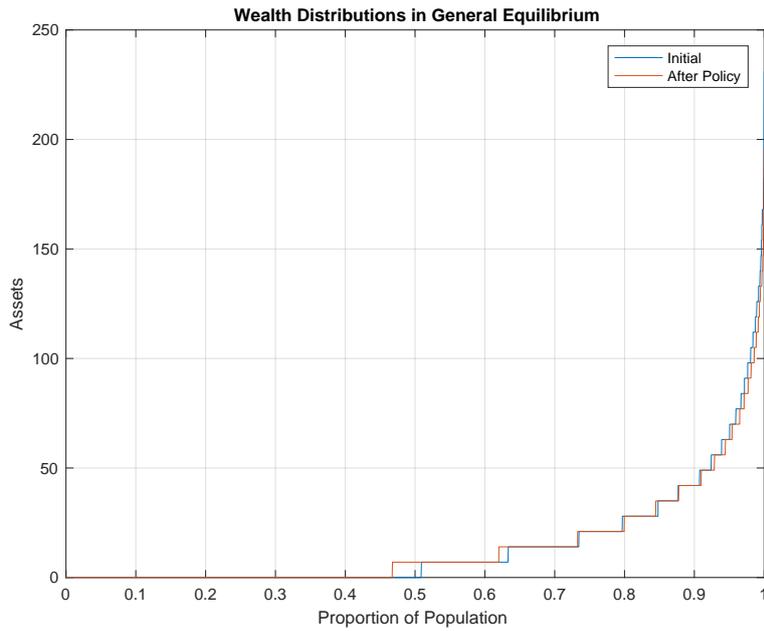
### 6.1 Effects of the Policy Reform

First of all, we present the wealth distribution before and after the policy reform:

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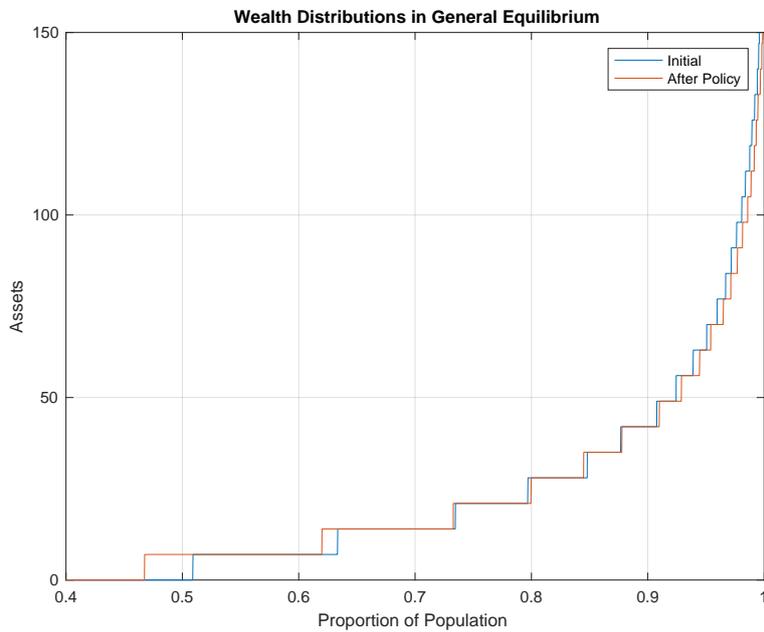
<sup>37</sup>This target was chosen in order to connect directly education and income in the model. However, it may be a concern that wages could be too high or low relative to  $\phi = 13.259$ . Average after-tax labor income generated by the model is 19.5 per period. On the other hand, average monthly income in 2011 Chile was 390,365 CLP according to the *Instituto Nacional de Estadísticas*, which would translate into a model income of 23.42, not too far. In any case, calibration with average income as target is carried out a robustness exercise in appendix C.

Figure 3:



We may zoom into this picture to observe the differences more accurately:

Figure 4:



What we can observe from this image is that assets are increased for a small part of the population in the 5th to 7th deciles of wealth (recall that assets and wealth are equivalent

in this model due to the financial constraint), and decreased for most of the population in the 10th decile. These changes will imply a decrease in the wealth gini as we will see, though a rather small decrease, as both distributions are quite close.

In order to explain the causes of this change in the wealth distribution, some moments of interest can be compared between the two steady states:

Table 3: Policy Reform Effects on Moments of Interest

	Before Policy	After Policy
<b>Wealth Gini</b>	0.737	0.711
<b>Aggregate Assets</b>	175.9	174.6
<b>Income Gini</b>	0.453	0.436
<b>HE Earnings Premium</b>	2.33	1.94
<b>HE Enrollment Rate</b>	37.6%	49.6%
<b>HE Dropout Rate</b>	42.1%	47.0%
<b>HE Attainment</b>	21.8%	26.2%
<b>Graduate Tax</b>		9.3%

Where the enrollment rate is the percentage of individuals in  $j = 0$  who opt for education instead of working. Of these individuals, the percentage who end up as dropouts is given by the dropout rate. This means that HE attainment equals the enrollment rate times 1 minus the dropout rate. The graduate tax corresponds to  $\tau_g$  as explained in subsection 4.5.<sup>38</sup>

First of all, aggregate assets<sup>39</sup> decrease but only by a very small margin. This could either suggest that precautionary savings and the timing of education expenditures are not relevant mechanisms, or that there are other mechanisms acting on aggregate assets. We discuss this issue in the next two subsections. Second, the enrollment rate has increased significantly, which indicates that less agents are liquidity constrained in

<sup>38</sup>From the model, the enrollment rate is  $\bar{H}$ , the dropout rate is  $\bar{D}$  and the attainment is  $\bar{H}(1 - \bar{D})$ .

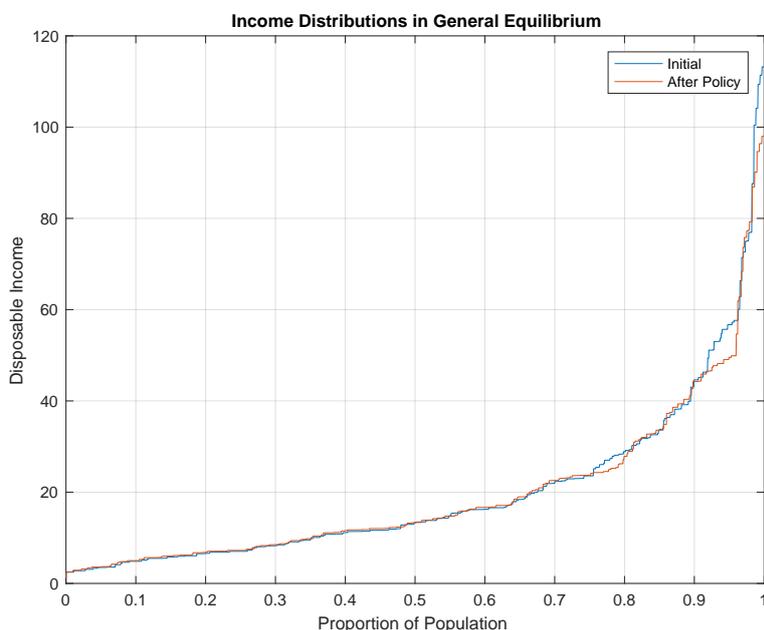
<sup>39</sup>It must be noted that this number is not comparable to actual aggregate assets in Chile in 2011, even while individual incomes and asset holdings are. This is because the model assumes a continuum of individuals of measure one in each generation or cohort. Aggregate assets in the model are calculated then as the sum across cohorts of the average assets in each cohort, which yields a completely different magnitude from Chilean aggregate assets in 2011, due to differences in population. Aggregate assets are only a measure used to compare between steady states of the model.

education. This is coupled with an increase in the dropout rate, which means that more low-ability individuals are entering as well. Both these outcomes result in a moderate increase in the population HE attainment, which increases 4.4%, suggesting that the loosening of liquidity constraints in education is stronger than any disincentive from the graduate tax. And this increase in attainment is a cause for the decrease in the earnings premium as argued in subsection 6.5, and also triggers a decrease in the income gini that translates into the decrease in the wealth gini that is observed.

It must be noted that all income data presented corresponds to after-tax income, and that includes the graduate tax. Therefore, a part of the fall in the earnings premium is simply because HE graduates are taxed with  $\tau_g$  while the rest are not. It is only a part because note that, if earnings from each group did not change at all, the observed fall due to the graduate tax would have been  $2.33(1 - 0.093) = 2.11$ . The rest of the fall up to 1.94 in the earnings premium is attributable to a fall in the before-tax earnings premium.

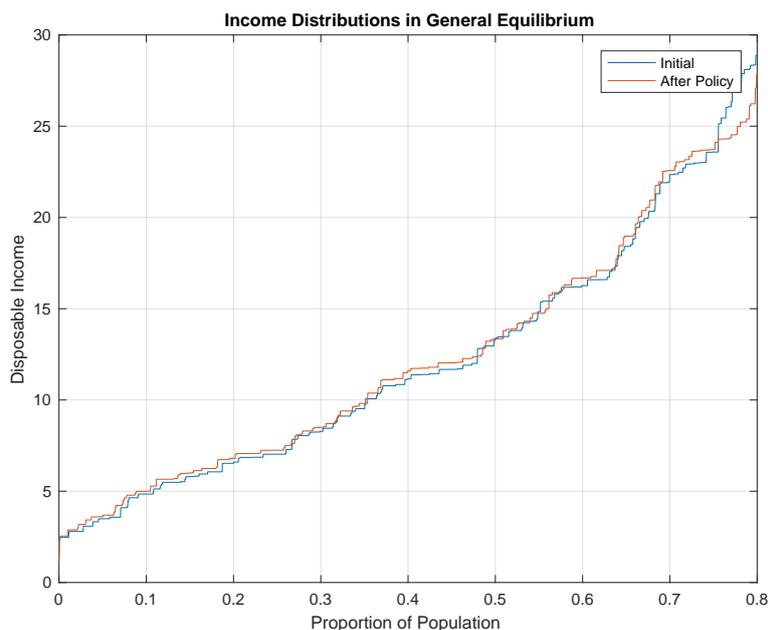
We may delve deeper into income data generated by the model to better understand these effects. We present the full distributions of disposable income:

Figure 5:



It is worthwhile zoom into the lower end of the distribution

Figure 6:



We can observe a slightly higher income after the policy reform for most of the lower end of the distribution, but a significantly lower income for some of the higher end. This can be further analyzed by looking at average disposable incomes and wages per efficiency unit  $w^e$  for each education group:<sup>40</sup>

Table 4: Income and Wage Effects of Policy Reform

	Before Policy	After Policy
<b>Average Skilled Income</b>	35.89	30.17
<b>Average Unskilled Income</b>	15.57	15.68
$w^S$	20.49	19.56
$w^U$	20.55	21.18

The general equilibrium adjustment of wages is relatively small, even though attainment rates are moderately higher after the policy reform. This can explain the differences in average incomes (taking into consideration the graduate tax lowers average skilled disposable income) and the differences observed in the income distribution: average unskilled

<sup>40</sup>Recall that  $w^U > w^S$  does not imply higher incomes for unskilled labor, because the provision of efficiency units is different for each education group (in this case, skilled labor generally provides more efficiency units).

income increases and average skilled income decreases.

These results also hold for almost all of the robustness checks in appendix C, which gives credit to the model structure for generating these mechanisms. The next step is to study more in depth each of the mechanisms in play. The next four subsections deal with this issue.

## 6.2 Precautionary Savings

In section 4 when explaining the model, we argued that precautionary savings could play a role in the wealth distribution, as uncertainty about the child's ability  $\theta_C$  could imply a higher savings rate than a deterministic environment in this regard. This suggests that aggregate assets could decrease after the policy reform. Since this variable barely moved, this explanation is called into question. In order to isolate this mechanism from the rest of the policy reform, we calculate a new steady state, where there is no uncertainty about a child's ability:  $\theta_C$  is known from the period  $j = 1$  in the parent's life cycle. All other aspects of this new steady state correspond to the model as presented in section 4 before the policy reform.

Formally, this means that the agent's problems from  $j = 1$  to  $j = 5$  (the working periods before the inter-vivos transfer) become:

$$V_j^e(a_j, \theta, \theta_C, z_j) = \max_{c_j, a_{j+1}} u(c_j) + \beta \mathbb{E}_z[V_{j+1}^e(a_{j+1}, \theta, \theta_C, z_{j+1})] \quad (31)$$

Subject to

$$\begin{aligned} c_j(1 + \tau_c) + a_{j+1} &= (1 - \tau_y)y_j + a_j(1 + r(1 - \tau_a)) \\ y_j &= w^e \varepsilon_j^e(\theta, z_j) \\ c_j, a_{j+1} &\geq 0 \\ z_{j+1} &\sim \Gamma_z(z_{j+1}|z_j) \end{aligned}$$

Where the only difference is the child's ability as a state variable. Also the HE student's problem changes to:

$$V_0^H(\hat{a}, \theta) = \max_{c_0, a_1} u(c_0) + \beta [\kappa(\theta) \mathbb{E}_{z, \theta}[V_1^S(a_1, \theta, \theta_C, z)] + (1 - \kappa(\theta)) \mathbb{E}_{z, \theta}[V_1^U(a_1, \theta, \theta_C, z_1)]] \quad (32)$$

Subject to

$$\begin{aligned} c_0(1 + \tau_c) + a_1 + \phi &= \hat{a} \\ c_0, a_1 &\geq 0 \\ \theta_C &\sim \Gamma_\theta(\theta_C|\theta) \end{aligned}$$

And analogously, if the agent chooses to work in  $j = 0$  he faces:

$$V_0^U(\tilde{a}, \theta, z_0) = \max_{c_0, a_1} u(c_0) + \beta \mathbb{E}_{z, \theta} [V_1^U(a_1, \theta, \theta_C, z_1)] \quad (33)$$

Subject to

$$\begin{aligned} c_0(1 + \tau_c) + a_1 &= (1 - \tau_y)y_0 + \tilde{a} \\ y_0 &= w^U \varepsilon_0^U(\theta, z_0) \\ c_0, a_1 &\geq 0 \\ z_1 &\sim \Gamma_z(z_1|z_0) \\ \theta_C &\sim \Gamma_\theta(\theta_C|\theta) \end{aligned}$$

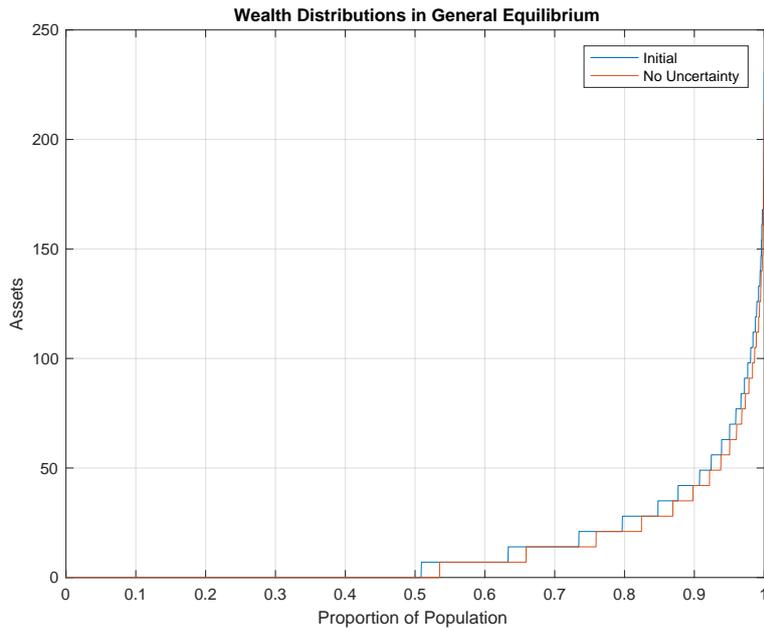
All of this means that uncertainty about the child's ability is only present in period  $j = 0$  of life cycle.<sup>41</sup> This eliminates precautionary savings in periods  $j = 1$  to  $j = 5$ , and arguably most precautionary savings in period 0 where there is still uncertainty, because the agent knows from the start he will have five periods to save in case he wants transfer a large sum to his offspring. Therefore, child ability uncertainty is not very relevant in choosing  $a_1$ .

The results support this hypothesis as is shown in the following picture featuring the wealth distribution calculated in this new steady state without child ability uncertainty, compared with the initial wealth distribution:

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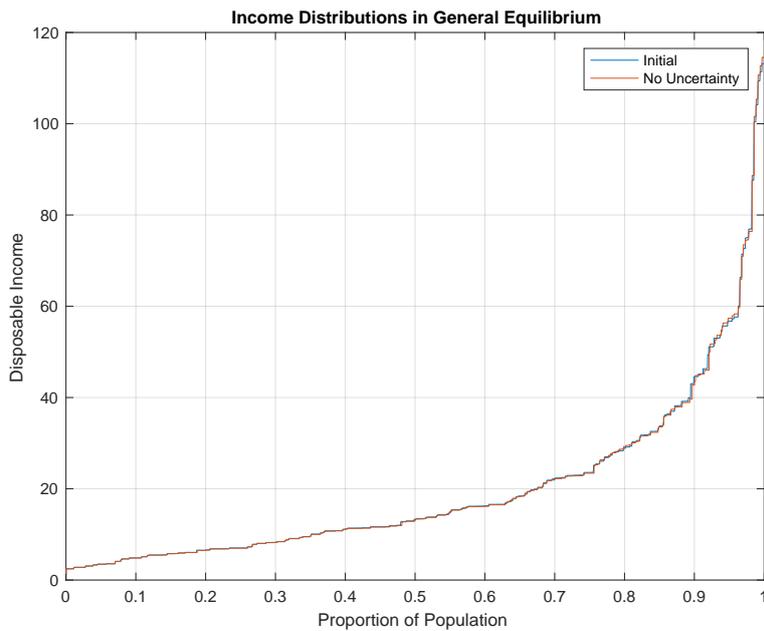
<sup>41</sup>This was assumed to ease the computation of the equilibrium, which would have been significantly more complicated if child's ability were a state variable in  $j = 0$ .

Figure 7:



This shows a decrease in assets by most of the population with positive assets. Aggregate assets fall to 154.4 from the previous value of 175.9 calculated in the initial steady state. And this is due to a decrease in the savings rate, as the income distribution is virtually the same between both steady states:

Figure 8:



From this exercise we learn that uncertainty about a child's ability is a relevant mechanism to generate savings. Therefore, there is possibly some other mechanism at work that causes aggregate assets to rise after the policy reform, netting out the effects of the reduced uncertainty. It could be that, since there are considerably more unskilled than skilled agents, the increase in unskilled income leads to a higher accumulation of assets in this group than the decrease in assets of skilled agents.

Another possibility is that education expenditure  $\phi$  is a relatively small part of the inter-vivos transfers. Note that child ability uncertainty is still present in the after-policy steady state. It might be still relevant, even if not for educational expenses in particular, but for the rest of the inter-vivos transfer. Then, only a small decrease in aggregate assets would be expected, which matches the results observed. This would imply that precautionary savings about educational expenses in specific are not relevant, but there are other reasons to save if uncertainty about child's ability is present.<sup>42</sup>

### 6.3 Timing of Education Expenditure

The next mechanism to take into consideration is the specific time in the life cycle when education expenditure takes place. In the initial steady state, due to liquidity restrictions in the first period, education is paid by agents in  $j = 6$ , i.e. 48 year-olds whose children just turned 18, and started their own life cycle in  $j = 0$ . Parents transfer  $\phi$  (and more) to their offspring should these decide to enter higher education.

After the policy reform, education expenditure is covered throughout the whole working period of skilled agents, from  $j = 1$  to  $j = 8$ , in the form of the graduate tax. In order to assess the effect of spreading out education expenditures throughout the life cycle, we compute a new steady state equilibrium after the policy reform where the graduate tax  $\tau_g$  is only applied to skilled agents in  $j = 6$ . Therefore, education expenditures are covered only in that period of the life cycle. The differences between this new steady state and the one after the policy reform calculated in 6.1 are mainly attributable to the timing of

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<sup>42</sup>Possibly, a parent might want to transfer more to a low-ability child because his lifetime income will be lower, therefore the marginal increase in value from transfers is higher than for high-ability children, consistent with decreasing marginal utility from consumption: a sort of intergenerational smoothing of consumption. Interestingly, this mechanism acts in the opposite direction of educational expenses, by which a higher ability children would receive more transfers in the initial steady state. If this is true, while the policy reform might reduce volatility of educational expenses, it might increase volatility of inter-vivos transfers overall, as educational expenses would no longer net-out some of the intergenerational smoothing of consumption, implying that the policy reform should generate more precautionary savings and thus aggregate assets. It is possible this might have worked together with a reduction of aggregate assets from the timing of educational expenses in order to generate the results shown previously. However, more research must be done in order to clarify this matter.

the graduate tax, which covers education expenditure.

Formally, every skilled agent's resource constraint during the working period is free of the graduate tax, except in  $j = 6$  where it is

$$c_j(1 + \tau_c) + a_{j+1} + \mathbf{a} = (1 - \tau_g)(1 - \tau_y)y_j + a_j(1 + r(1 - \tau_a)) \quad (34)$$

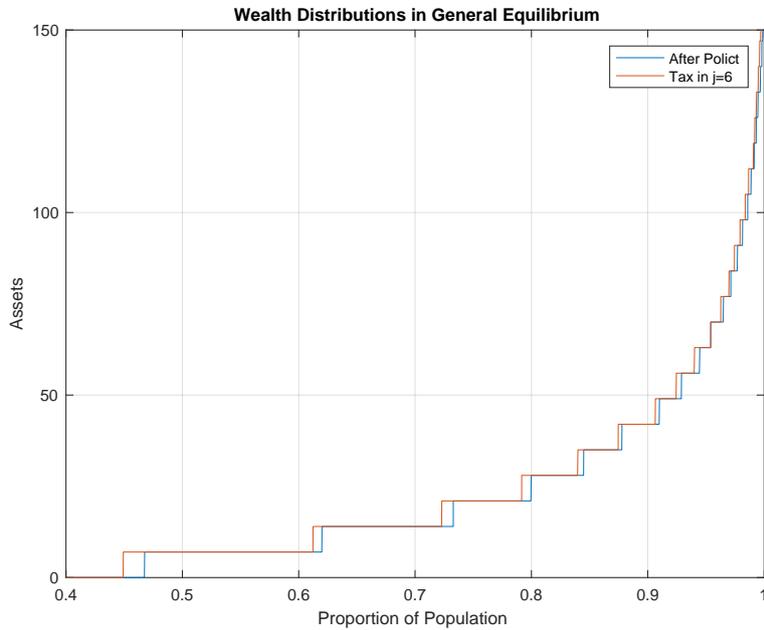
Where  $\mathbf{a}$  are inter-vivos transfers, as  $j = 6$  is the period when these are made. Naturally,  $\tau_g$  will be much higher in this steady state, as the taxable base diminishes substantially. This is also a highly unrealistic scenario, but it is not meant to provide a simulation of what could actually happen, it should only be interpreted as an exercise to learn about the mechanisms at play in the policy reform studied.

Lastly, the government budget constraint changes to

$$\phi \bar{H} = \tau_g(1 - \tau_y)w^S \int_{e=S, j=6} \varepsilon_i di \quad (35)$$

This results in the following wealth distribution (already zoomed in to where changes occur):

Figure 9:



Compared to the after-policy reform equilibrium, assets are higher if the graduate tax is charged in  $j = 6$ . Respectively, aggregate assets are 174.6 and 182.2, indicating that

concentrating education expenditures in a late period of the life cycle results in higher savings, consistent with the mechanism posited in section 4 of timing of education expenditure. This suggests again that there are other mechanisms at play netting out this effect and the one of reduced precautionary savings, since both these mechanisms are shown to be relevant in the two exercises carried out.

## 6.4 Liquidity Constraints

Both previous mechanisms focused on the savings aspect of the wealth distribution: given fixed income, how much is consumed and how much is accumulated as assets. This subsection intends to explain the increase in higher education attainment, which sets off a decrease in the earnings premium, income gini and wealth gini. In order to study the presence and relevance of liquidity constraints when deciding to enter higher education, we calculate a new steady state where agents are allowed to borrow.

In this new steady state, agents in  $j = 0$  that decided to study face a liquidity constraint of  $a_1 \geq \bar{a}_1$  instead of  $a_1 \geq 0$ , where  $\bar{a}_1 < 0$ . In order to allow for some time to pay the debt, in period  $j = 1$  agents face the liquidity constraint  $a_2 \geq \bar{a}_2$  and in  $j = 2$  they face  $a_3 \geq \bar{a}_3$ , where  $\bar{a}_2, \bar{a}_3 < 0$  and  $|\bar{a}_1| > |\bar{a}_2| > |\bar{a}_3|$ . All of this just means that agents may borrow in periods  $j = 0, 1, 2$  in decreasing amounts over time.<sup>43</sup> This translates to the following problem of a working agent in  $j = 1, 2$ :

$$V_j^e(a_j, \theta, z_j) = \max_{c_j, a_{j+1}} u(c_j) + \beta \mathbb{E}_z[V_{j+1}^e(a_{j+1}, \theta, z_{j+1})] \quad (36)$$

Subject to

$$\begin{aligned} c_j(1 + \tau_c) + a_{j+1} &= (1 - \tau_y)y_j + a_j(1 + r(1 - \tau_a)) \\ y_j &= w^e \varepsilon_j^e(\theta, z_j) \\ c_j &\geq 0, \quad a_{j+1} \geq \bar{a}_{j+1} \\ z_{j+1} &\sim \Gamma_z(z_{j+1}|z_j) \end{aligned}$$

After calculating this new equilibrium, two results stand out. Comparing to the initial steady state of active liquidity constraints, higher education attainment rose from 21.8% to 26.6%, and the dropout rate was reduced strongly from 42.1% to 27%. These two results together imply that most of the new students are high ability students, as they have smaller chances of dropping out. It also means that liquidity constraints are a relevant mechanism in determining the decision to enter higher education in this model, as

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<sup>43</sup>Agents who chose to work the first period may not borrow.

loosening them increases attainment.

It is worth noting however, that even though allowing students to take up debt and the policy reform of free higher education both loosen liquidity constraints, they do so in a different manner. Because in this steady state, if the agent acquires debt but can't pay it in the next period even with all his income (for example, if he had a bad productivity shock, or dropped out and received low income as unskilled labor), negative consumption implies utility of  $-\infty$ , as imposed in the computational model. This means that if agents have a possibility of not paying back the debt they will not risk the chance, and will decide not to study. However, there is no risk of not being able to pay back in the policy reform: if the agent does not graduate, he simply does not pay the tax  $\tau_g$ . And even if he had a bad productivity shock, the tax is applied as a constant percentage of income, never allowing for the case of an agent ending up with negative consumption. This means that the policy reform is a safer alternative for low-skilled students, which explains why the dropout rate increases when implementing the policy reform relative to the initial steady state (contrary to allowing student debt, which decreases the dropout rate). An interesting case for studying is allowing for a softer form of credit to lift liquidity constraints, for example enabling a default in some cases or subsidizing the loan to lower the interest rate, as is done with many student credit programs. That would allow us to surpass the difficulties discussed in this paragraph when comparing to the policy reform, and would probably yield even higher educational attainment, but this is beyond the scope of this investigation.

Regarding the potential disincentive from the graduate tax due to high dropout rates: this mechanism is not directly addressed in the absence of a steady state which could isolate its effects. However, we may guess that it is relevant, as education attainment is higher in the case of enabling student credit than after the policy reform: 26.6% versus 26.2% respectively. This is not very much, but if what was argued in the previous paragraph is true, then softer credits could provide much larger differences and could evidence a significant disincentive to enter higher education by the graduate tax with high dropout rates.

## 6.5 General Equilibrium Adjustment of Wages

The final exercise done in order to analyze the mechanisms at play in the policy reform is to calculate a partial equilibrium. This is simply done by calculating the after-policy steady state holding the wages per efficiency unit  $w^e$  fixed at their initial level, before the policy reform. The results are the following:

Table 5: Policy Reform Effects on Partial and General Equilibrium

	Before Policy	Partial Eq.	After Policy
<b>Wealth Gini</b>	0.737	0.728	0.711
<b>Aggregate Assets</b>	175.9	171.1	174.6
<b>Income Gini</b>	0.453	0.446	0.436
<b>HE Earnings Premium</b>	2.33	2.13	1.94
<b>HE Enrollment Rate</b>	37.6%	57.7%	49.6%
<b>HE Dropout Rate</b>	42.1%	48.8%	47.0%
<b>HE Attainment</b>	21.8%	29.5%	26.2%
$w^S$	20.49	20.49	19.56
$w^U$	20.55	20.55	21.18
<b>Graduate Tax</b>		9.4%	9.3%

As can be expected, enrollment rates and higher education attainment is higher in partial equilibrium than in general equilibrium. This is because wages have not yet adjusted:  $w^S$  is higher than it will be in general equilibrium, and  $w^U$  lower. Therefore, it is very attractive to enter higher education given by the enrollment and attainment rates (even if ability is not very high which is reflected in the high dropout rate in partial equilibrium). Also expected is the fall in the HE earnings premium, due to the graduate tax. But it is more important to note that it is still higher than the earnings premium in general equilibrium, the last column, which is due to the wage adjustment. This means that the general equilibrium is also a relevant feature to consider on the effects of the wealth distribution: a higher education attainment decreases  $w^S$  and increases  $w^U$ , which reduces the income and wealth gini. The wage adjustment also reduces the gain in HE attainment in equilibrium. From this exercise we learn that the general equilibrium in wages constitutes a relevant mechanism for the question at hand.

We can also observe a larger fall in aggregate assets in partial equilibrium than in general equilibrium. This lends some credit to the possibility that a higher unskilled wage increases assets more than a lower skilled wage decreases assets, because the unskilled population is higher than the skilled. This mechanism might net out some of the fall in aggregate assets due to precautionary savings and timing of education expenditure.

One final discussion of the results entails the magnitude of the change in the income and wealth gini indexes. The reader might find the effect of the policy reform on these indexes rather small, overall or when compared to the change in the earnings premium or higher education attainment, considering such a large change in educational system policy. While it is hard to interpret the magnitude of a change in a gini index, if we consider them to be small in this thesis, the reason is probably the structure of efficiency units in the model and the resulting calibration. It is possible that inequality in income and wealth in the population is mostly driven by individual characteristics (in this model: ability, productivity shocks, and age) than differences between education groups. These characteristics are quite relevant in income, as given by the calibration in section 5, and they are not altered by the policy reform. Therefore while the increase in higher education attainment and lower earnings premium might help reduce inequality, they don't make a large contribution in this exercise.

## 7 Conclusions

This thesis has investigated the possible long-run effects on the wealth distribution of implementing universal free higher education financed by a graduate tax in Chile. It has done so by building an OLG Bewley model which incorporates the most important mechanisms at hand and running a simulation of a steady state in which the policy reform is implemented. The results show an increase in wealth for the lower end of the distribution, and a decrease for the higher end, with only a minor decrease in aggregate wealth. The decrease in wealth inequality can be explained by the reduction in income inequality given by a lower earnings premium triggered by a higher proportion of population graduated from higher education. A sensitivity analysis confirms robustness of these results to specific calibration of the model. Further investigation by computing additional steady states to isolate mechanisms has shown that liquidity constraints in education are loosened by the reform and the general equilibrium adjustment of wages is relevant for the wealth distribution. These additional exercises also suggest that precautionary savings and the timing of educational expenditures are relevant mechanisms, but are not alone in determining savings rates and aggregate assets.

As for further work, the author's opinion is that the natural extension to this thesis is to model student aid in the form of subsidized loans and grants. These could help in making a more realistic scenario in terms of present liquidity constraints, and shed some more light in the possible disincentives the graduate tax could have. A second, more ambitious possibility is building a short-term model featuring an inelastic educational supply.

Then, short term effects of the policy would probably not have large consequences on educational attainment or the wage premium, but possibly a better allocation of ability into higher education through the elimination of liquidity constraints, if an efficient selection mechanism for higher education applicants is in place. A third alternative could be diving into the heterogeneity of educational supply. A simple approach might be to differentiate between short term vocational programs provided by technical institutions, and longer general programs from universities. Later, institution or program heterogeneity in quality could play a role as well.

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# Appendix

## A Section 3 Data

### A.1 Data Definitions and Sources

- *Household Disposable Income Gini*: Income distribution data refer to the total population and are based on equivalised household disposable income, i.e. disposable income (after taxes) adjusted for household size. The Gini coefficient takes values between 0 (where every person has the same income), and 1 (where all income goes to one person). 2013 data for Chile, 2014 for the USA, 2013 for Norway, and the OECD average includes country data between 2012 and 2014 according to data availability. Source: *Income Inequality Update, November 2016*, OECD
- *Household Wealth Gini*: Data corresponds to the year 2000 for all three countries. In the case of the USA, the Survey of Consumer Finances 2001 is used. With Norway, the Income and Property Distribution Survey. And finally, the authors argue that there was no available data for Chile and constructed the wealth distribution by regression-based imputations. Provided by Davies et al. (2011).
- *Public Expenditure on H.E. as % of GDP*: Public expenditure on tertiary educational institutions, as % of GDP. Public expenditure figures presented here exclude undistributed programmes. Including public subsidies to households attributable to educational institutions, and direct expenditure on educational institutions from international sources. In the case of Chile, not including international sources. Year of reference is 2013 for USA and Norway, 2014 for Chile. OECD average includes 2012, 2013 and 2014 as years of reference. Source: Table B2.3 Education at a Glance (2016).
- *Private Expenditure on H.E. as % of GDP*: Private expenditure on tertiary educational institutions, as % of GDP. Net of public subsidies attributable to educational institutions. Year of reference is 2013 for USA and Norway, 2014 for Chile. OECD average includes 2012, 2013 and 2014 as years of reference. Source: Table B2.3 Education at a Glance (2016).
- *Adults Graduated from H.E.*: Percentage of 25-64 year-olds that have attained tertiary education, either short-cycle tertiary, bachelor's degree, or higher. Data classification refers to ISCED 2011. Year of reference is 2015 for USA and Norway,

2013 for Chile. OECD average includes 2013, 2014 and 2015 as years of reference. Source: Table A1.2 Education at a Glance (2016).

- *H.E. Earnings Premium*: Relative earnings of full-time full-year workers. 25-64 year-olds with income from employment; upper secondary education = 1. For USA, Index 100 refers to the combined ISCED levels 3 and 4 of the educational attainment levels in the ISCED 2011 classification. The indicator is based on the data collection on education and earnings by the OECD LSO (Labour Market and Social Outcomes of Learning) Network that takes account of earnings from work for individuals working full-time full-year as well as part-time or part-year during the reference period. For further methodology details, see Education at a Glance 2016 pages 122-123. Year of reference is 2014 for USA and Norway, 2013 for Chile. OECD average includes 2010, 2012, 2013 and 2014 as years of reference. Source: Table A6.1 Education at a Glance (2016).
- *Parent Child Schooling Correlation*: Sample correlation between years of schooling of parent on child are taken for each five-year birth cohort, and then averaged across cohorts. Years of schooling are taken from survey data from each country, survey year is 1998-1999 for Chile, 1998 for Norway and 1994-2000 for USA. See Hertz et al. (2007) for further details and advantages of this methodology.
- *Parent Child Schooling  $\beta_s$* : Bivariate regressions (of the kind shown in section 3) between years of schooling of parent on child are run for each five-year birth cohort, and then the regression coefficients  $\beta$  averaged across cohorts. Years of schooling are taken from survey data from each country, survey year is 1998-1999 for Chile, 1998 for Norway and 1994-2000 for USA. See Hertz et al. (2007) for further details and advantages of this methodology

## A.2 Intergenerational Correlation of Education

As stated in section 3, it may concern the reader that while the last two variables evidence intergenerational correlation of education in general, they do not specifically represent intergenerational correlation of tertiary education. A more indirect measure is now presented for Chile and its benchmarks:

Table 6:

	Chile	USA	Norway	OECD
T.E. attainment given S.E. parents	37%	33%	38%	39%
T.E. attainment given T.E. parents	77%	61%	65%	67%
Difference	40%	28%	27%	28%

How to read this table: In Chile, among 25-44 year-old non-students whose parents have upper secondary education and whose parents are both native-born, 37% attained tertiary education. On the other hand, among 25-44 year-old non-students whose parents have tertiary education and whose parents are both native-born, 77% attained tertiary education. Parents' educational attainment should be understood as the highest level of education of either parent.

In this case, a rough measure of intergenerational correlation in tertiary education (TE) is the increase in the proportion of adults attaining TE education if their parents attained TE instead of SE. Using a frequentist approach of probability, it could be interpreted as the increase in the chances of attaining TE if parents attained TE. If this increase is zero, that would mean parent's background does not influence child educational attainment at all, the opposite if the increase were 100%.

The third row gives such increase. It is significantly higher in Chile than in all benchmarks, indicating a higher intergenerational correlation, specifically in tertiary education. Recall that we are using the terms higher education and tertiary education indistinctly to mean all forms of formal education after secondary, be it vocational or general.

But even this indicator may be criticized as too rough to provide an accurate depiction of intergenerational correlation in TE. For further analysis, see Sapelli (2009a) who studies intergenerational mobility in Chile. In particular, his graph 7d shows significant and increasing persistence in TE attainment. Sapelli attributes this increase in persistence to financial constraints not at the time of college entry of the child, but at the time of his birth, thus suggesting the importance of early interventions in education. That would translate into a higher correlation of ability  $\theta$  between parent and child in our model. Regardless, other studies find that financial constraints are significant in Chile, as shown in section 3.

## B Computation Methodology

The calculation of the general equilibrium initial steady state is done with the following computational algorithm programmed in MATLAB:

1. Posit a guess for aggregate skilled and unskilled human capital,  $H^S$  and  $H^U$ . These guesses imply specific wage levels  $w^S$  and  $w^U$ .
2. Posit a guess for the initial value function  $V_0^*(\hat{a}, \tilde{a}, \theta)$
3. Solve through induction the agents problems from  $j = 12$  to  $j = 0$ , obtaining numerical estimates of the value functions. Note that a previous guess of  $V_0^*$  is needed to solve the problem in  $j = 6$ .
4. Solving the problem in  $j = 0$  yields a new estimate for  $V_0^*$ . If the new  $V_0^*$  is too different from the previous guess, use it as a new guess and repeat step 3. Otherwise, continue.
5. Posit a guess for the aggregate distribution of inter-vivos transfers for  $n$  agents.  $n$  will be the number of agents simulated. In all exercises carried out,  $n = 100,000$ .
6. Simulate the life cycles of the  $n$  agents, using the policy functions obtained in step 4. Note that this needs a guess for the distribution of inter-vivos transfers. The agents must have random idiosyncratic shocks, ability and graduation according to the structure detailed in section 5.<sup>44</sup>
7. Step 6 yields a new distribution of inter-vivos transfers. If the new distribution is too different from the previous guess, use it as a new guess and repeat step 6. Otherwise, continue.
8. Completing step 7 means the partial equilibrium has been found, but this results in new levels of aggregate human capital. If these levels are too different from the guess, update the guess, obtain new wages and return to step 2. Otherwise, a fixed point has been achieved and the general equilibrium has been found.

Once the model is calibrated, the post-reform general equilibrium must be calculated. This is done adding one more loop to the previous algorithm, because a guess must be posited on the graduate tax rate, which will be used to calculate value functions and simulate agents to estimate a general equilibrium. If the government budget is not balanced (revenue and expenditure can be easily calculated), the tax rate must be updated

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<sup>44</sup>This means shocks must use their transition matrix, as well as ability which must consider the intergenerational link.

and a new general equilibrium must be calculated. Once a general equilibrium with a balanced budget<sup>45</sup> is achieved, the calculation of the post-reform steady state equilibrium is complete, and results can be obtained.

## C Robustness Exercises

This section presents a series of alternate scenarios for the model and the calibration. In each case, the calibration exercise summarized in table 2 is carried out in an attempt to match target moments. However, greater care was taken in the main calibration exercise than in these additional exercises, therefore moments are not as well matched in the following initial steady states. Nevertheless, these exercises were successful in their purpose: the results obtained in section 6 hold for all alternate scenarios, with only one exception.<sup>46</sup> The results are a decrease in the wealth gini, income gini, earnings premium, skilled wage and very slight decrease in aggregate assets, as well as a rise in unskilled wage, enrollment, dropouts and attainment.<sup>47</sup>

### C.1 Closed Economy

This analysis considers two more conditions for the stationary equilibrium described in 4.4

5. The asset market clears:

$$K = \sum_{j=1}^{12} \int a_{ij} di \quad (37)$$

6. The goods market clears:

$$\sum_{j=0}^{12} \int c_{ij} di + \delta K + G + \sum_{j=9}^{12} p + \phi \bar{H} = F(K, \mathcal{H}) \quad (38)$$

Where it must be noted that the interest rate is determined so that equation 37 holds. In the computational algorithm, this means adding another loop by positing an interest rate guess and checking whether capital demand is sufficiently similar to aggregate assets. The results are the following:

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<sup>45</sup>Note that a perfectly balanced budget is impossible to achieve, a threshold for acceptable levels of budget imbalance must be used.

<sup>46</sup>When  $\alpha = 0.52$ , aggregate assets rise very slightly with the policy reform.

<sup>47</sup>Note that since calibrations are different for each exercises, comparison between moment values of different exercises does not have much valid information. The important comparison is between the initial steady state and after the policy reform, for each exercise separately.

Table 7: Closed Economy Policy Reform Effects

	Before Policy	After Policy
<b>Wealth Gini</b>	0.671	0.645
<b>Aggregate Assets</b>	285.1	283.2
<b>Income Gini</b>	0.484	0.469
<b>HE Earnings Premium</b>	2.47	2.07
<b>Skilled Wage</b>	19.62	18.68
<b>Unskilled Wage</b>	20.96	21.27
<b>HE Enrollment</b>	42.36%	53.62%
<b>HE Dropouts</b>	44.54%	48.84%
<b>HE Attainment</b>	23.49%	27.43%
<b>Annual Interest Rate</b>	4.38%	4.56%
<b>Graduate Tax</b>		8.88%

In this equilibrium, it must be noted that the author could not match the wealth gini properly: there is a significant difference to the target of 0.777. However, all the main results hold, and one thing stands out: aggregate assets fell and the interest rate rose.<sup>48</sup> Since this is a closed economy, it is likely that capital supply suffered a fall, because that imbalance that can be corrected by a rise in the interest rate and a fall in aggregate assets which are equal to the equilibrium amount of capital in the economy. This gives strength to the mechanisms of precautionary savings and education expenditures, which probably generated the fall in capital supply.

## C.2 Mean Income as Calibration Target

It is a valid concern to think average income in the population is a more important target to match than private expenditure in HE as a percentage of GDP. Therefore, another initial steady state is calibrated to match this target.

According to the *Instituto Nacional de Estadísticas*, the average monthly income of workers in Chile in 2011 was 390,365 CLP, which translates to 23,421,900 CLP in five years. As the unit of measure in the model is million CLP, the calibration target was 23.42 for average income across all the agents that were currently working in the model. The model value obtained in the calibration exercise was 23.69. Wealth gini proved harder to match than in the main exercise, but the results obtained were the standard:

<sup>48</sup>The annual interest rate is presented to allow for easier comparison to other steady states, however this is extracted from the five-year interest rate determined endogenously in the model.

Table 8: Policy Reform Effects, calibrating by  $\bar{y}$ 

	Before Policy	After Policy
<b>Wealth Gini</b>	0.717	0.702
<b>Aggregate Assets</b>	202.8	201.2
<b>Income Gini</b>	0.442	0.430
<b>HE Earnings Premium</b>	2.42	2.12
<b>Skilled Wage</b>	23.81	23.34
<b>Unskilled Wage</b>	24.89	25.23
<b>HE Enrollment</b>	38.24%	45.82%
<b>HE Dropouts</b>	40.31%	45.84%
<b>HE Attainment</b>	22.83%	25.17%
<b>Graduate Tax</b>		7.27%

### C.3 Utility Discount Factor

It may be a concern that parameters  $\beta$  and  $r$  are calibrated separately. This is done so because in a context of individual uncertainty and heterogeneous agents, aggregate outcomes do not necessarily come from the sum of individual outcomes, as opposed to a representative agent model. Further, because this is an OLG model without bequests, asset holdings do not diverge to zero or  $\infty$  if some specific relation for  $\beta$  and  $r$  is not satisfied, as is shown by the next exercises with a higher and lower interest rate. Nevertheless, in order to determine  $\beta$  with a standard procedure, it is assumed that in steady state aggregate consumption is constant and deterministic, and a standard euler equation yields

$$\beta = \frac{1}{1 + r(1 - \tau_a)} \quad (39)$$

Using the values for  $r$  and  $\tau_a$  chosen for the baseline exercise. This yields the standard results:

Table 9: Policy Reform Effects with alternate  $\beta$ 

	Before Policy	After Policy
<b>Wealth Gini</b>	0.709	0.679
<b>Aggregate Assets</b>	233.9	223.2
<b>Income Gini</b>	0.471	0.450
<b>HE Earnings Premium</b>	2.41	1.98
<b>Skilled Wage</b>	19.95	19.40
<b>Unskilled Wage</b>	20.89	21.31
<b>HE Enrollment</b>	41.63%	52.74%
<b>HE Dropouts</b>	44.88%	49.81%
<b>HE Attainment</b>	22.95%	26.47%
<b>Graduate Tax</b>		9.41%

#### C.4 Higher Interest Rate

An alternative value for the annual interest was chosen in order to test the robustness of results to this parameter calibration. A series of real interest rates for Chile was created from two variables. The nominal interest rate for each year was obtained from the lending interest rate from Chile provided by the World Bank, defined as the bank rate that usually meets the short- and medium-term financing needs of the private sector. Inflationary expectations were obtained from the *Encuesta de Expectativas Económicas* provided by the Central Bank of Chile: they are the expected percentage increase in the consumer price index 12 months ahead of the moment of the interview, according to a number of relevant actors surveyed. The real interest rate then is calculated as the nominal interest rate minus the inflationary expectations. An average is calculated over years 2000-2015 resulting in an annual real interest rate of 5.4%. This is set as a model parameter (recall that for all exercises this is a small open economy except for C.1) and the exercise carried out. Wealth gini was very hard to match again, indicating the interest rate is an important determinant, but the standard results were obtained:

Table 10: Policy Reform Effects with higher  $r$ 

	Before Policy	After Policy
<b>Wealth Gini</b>	0.658	0.623
<b>Aggregate Assets</b>	238.1	230.2
<b>Income Gini</b>	0.429	0.409
<b>HE Earnings Premium</b>	2.27	1.70
<b>Skilled Wage</b>	19.93	18.78
<b>Unskilled Wage</b>	18.70	19.33
<b>HE Enrollment</b>	36.80%	55.22%
<b>HE Dropouts</b>	46.12%	53.32%
<b>HE Attainment</b>	19.83%	25.78%
<b>Graduate Tax</b>		12.49%

## C.5 Lower Interest Rate

Another alternative value for the interest might be used: the interest rate for inflation-linked secondary market bonds from the Central Bank of Chile (BCU bonds in UF with one year maturity). These have a very low interest rate, as it abstracts from inflation and are very low-risk bonds. The average interest rate for years 2008-2016 (the available data) is 1.53%. Now wealth gini proved very easy to match, and results were standard as well:

Table 11: Policy Reform Effects with lower  $r$ 

	Before Policy	After Policy
<b>Wealth Gini</b>	0.770	0.752
<b>Aggregate Assets</b>	177.8	173.4
<b>Income Gini</b>	0.466	0.451
<b>HE Earnings Premium</b>	2.40	2.07
<b>Skilled Wage</b>	23.12	21.91
<b>Unskilled Wage</b>	23.74	24.65
<b>HE Enrollment</b>	40.33%	48.42%
<b>HE Dropouts</b>	44.75%	43.71%
<b>HE Attainment</b>	22.28%	27.26%
<b>Graduate Tax</b>		7.2%

## C.6 Higher Share of Capital in Production

While  $\alpha$  was chosen to be 0.33 in the baseline exercise as a standard value used in the literature, the Chilean Central Bank uses a value of 0.52 in their growth accounting exercises (as stated in the *Informe de Política Monetaria*, September 2016). This parameter value is used to carry out another robustness check, and almost all results hold this time, except that aggregate assets show a very small increase, instead of a very small decrease:

Table 12: Policy Reform Effects with higher  $\alpha$

	Before Policy	After Policy
<b>Wealth Gini</b>	0.768	0.729
<b>Aggregate Assets</b>	132.7	133.5
<b>Income Gini</b>	0.466	0.441
<b>HE Earnings Premium</b>	2.31	1.79
<b>Skilled Wage</b>	15.38	14.58
<b>Unskilled Wage</b>	15.44	16.00
<b>HE Enrollment</b>	38.93%	53.05%
<b>HE Dropouts</b>	42.84%	47.51%
<b>HE Attainment</b>	22.25%	27.85%
<b>Graduate Tax</b>		12.59%

## C.7 Higher Depreciation Rate

The depreciation  $\delta$  was chosen to be 4.11% annually in the baseline exercise according to Penn World Tables data. However, it may be higher according to other sources. In particular, according to the *Ministerio de Hacienda, Dirección de Presupuestos* in Chile, it was 5,5% in 2011 and 8,3% in 2010 (probably because of the earthquake that struck Chile that year). While 5,5% is probably a better estimate of the depreciation rate for any normal year, we carry out another robustness check using the annual depreciation rate of 2010 in order to carry out a harder robustness test. The results hold, as with all other exercises:

Table 13: Policy Reform Effects with higher  $\delta$

	Before Policy	After Policy
<b>Wealth Gini</b>	0.738	0.721
<b>Aggregate Assets</b>	169.5	164.0
<b>Income Gini</b>	0.465	0.450
<b>HE Earnings Premium</b>	2.47	2.01
<b>Skilled Wage</b>	18.73	17.71
<b>Unskilled Wage</b>	18.61	19.29
<b>HE Enrollment</b>	35.82%	51.41%
<b>HE Dropouts</b>	43.47%	50.33%
<b>HE Attainment</b>	20.25%	25.54%
<b>Graduate Tax</b>		10.16%