How the Wage-Education Profile Got More Convex: Evidence from Mexico.*

Chiara Binelli†

University of Southampton, IFS and RCEA

This draft: 24 March 2012.

Abstract

In the 1990s, in many countries, log wages became a more convex function of education: returns to college increased and returns to intermediate education declined. This paper argues that an important cause of this convexification was a two-stage demand-supply interaction: an increased demand for workers with college and intermediate education stimulated a supply response; the increased supply of intermediate-educated workers further increased the demand for college-educated workers, because these two types of labour are complementary. This argument is supported by an empirical equilibrium model of savings and educational choices for Mexico, where the degree of convexification was amplified by loosening credit constraints.

Key Words: Wage Inequality, Human Capital, Empirical Equilibrium Model, Mexico.

JEL Codes: J31, J24, J23.

*I thank Orazio Attanasio, Nicola Pavoni, Debraj Ray, Margaret Stevens, Chris Taber and Adrian Wood for helpful comments and suggestions. Previous versions of this paper circulated under the title "Returns to Education and Increasing Wage Inequality in Latin America" and “The Demand-Supply-Demand Twist: How the Wage Structure Got More Convex”. All errors are mine.

†Address: Economics Department University of Southampton. Email: C.Binelli@soton.ac.uk

1 Introduction

In the 1990s in many countries the wage-education profile convexified: returns to college increased while returns to intermediate education decreased or remained substantially unchanged.[1] This pattern has been documented both for high-income and for low- and middle-income countries.[2] Efforts to explain the convexification have focused on the US and two main explanations have been proposed: increasing returns to college in a model where returns to schooling are heterogeneous (Deschenes 2002 and Lemieux 2006), and different degrees of complementarity/substitutability between computer technology, skilled and unskilled labour within a "task-based technical change" model (Autor, Katz and Kearney 2006).[3] The wage convexification in the US happened at a time of modest changes in the relative supply of workers with high school and college education (Goldin and Katz 2007). Consistently, both previously proposed explanations have taken the supply of labour as exogenously given.

This paper relaxes the assumption of exogenous labour supply and suggests an alternative though not necessarily inconsistent explanation of the convexification, which exploits the substantial changes in the demand and in the supply of labour that happened in several countries where wages convexified. The argument is based on a two-way interaction between the demand and the supply of workers with different levels of education. An initial rise in the demand for workers with intermediate and college education increased the returns to both these two types of educated workers and gave incentives to invest in human capital. A reduction of credit constraints allowed the supply of intermediate-educated workers to rise, which further increased the demand for college-educated workers since workers with

[1] Consistently with the convexification of the wage-education profile, the distribution of wages has been characterized by divergent trends in upper- and lower-tail inequality: the 90th-50th percentile ratio of hourly wages increased, while the 50th-10th ratio declined or increased much less (e.g. Goos and Manning 2003 for the UK; Goldin and Katz 2007, Autor, Katz and Kearney 2006, Anderson, Tang and Wood 2006 and Wood 2002 for the US; Binelli and Attanasio 2010 for Mexico).

[2] Among the others, Lemieux (2006, 2007) and Deschenes (2002) for the US; Lopez Boo (2008) for Argentina; Metha, Felipe, Quising and Camingue (2007) for Thailand, Philippines and India; Liu (2006) for Vietnam; Söderbom, Teal, Wambugu and Kahyarara (2006) for Kenya and Tanzania; Bouillon, Legovini and Lustig (2005) for Mexico; Blom, Holm-Nielsen and Verner (2001) for Brazil; Schady (2001) for the Philippines.

[3] The convexifcation of the wage-education profile has also been studied in the context of the long run theory of equilibrium wage functions: in an equilibrium model of savings and occupational choices, Mookherjee and Ray (2010) derive the theoretical prediction of a convex relationship between the skill-intensity of an occupation and its marginal rate of return so that "the return to human capital is endogenously nonconcave".

intermediate and with college education are complementary in production. As a result, returns to college increased and returns to intermediate education declined.

The argument is investigated in the context of Mexico, a middle-income country where the convexification was very pronounced: between 1987 and 2002 the wage gap between workers with higher (college or more) and intermediate education increased by 73%, and the wage gap between workers with intermediate and basic (compulsory) education declined by 15%. Importantly, these wage changes happened at a time of significant changes in the demand and in the supply of labour: while the demand for educated workers increased by over 1.3% a year, the proportion of workers with intermediate and with higher education increased, respectively, by around 15% and 7%.

These supply changes could in theory have caused the convexification by altering the composition of workers due to a more educated and relatively younger workforce. However, I show that this was not the case for either observable (age effects) or unobservable (ability or quality of the workers) characteristics. Then, I develop a model to quantify the importance of changes in the prices of education as the proximate cause of the convex shift. The setting is an incomplete market, dynamic model of savings and educational choices where the interest rate is taken as given and the aggregate production function is modelled as a flexible CES specification that allows for different elasticities of substitution between three aggregate human capitals - basic, intermediate and higher education. Savings and education choices are made by altruistic parents that face credit constraints.

I estimate the wage equations, the production function, and the distribution of wealth and education in 1987 using micro data from Mexico, and I calibrate the rest of parameters. I find that the substitution elasticities between human capital aggregates are consistent with the complementarity between intermediate and higher education. I then use model's simulations to study the determinants of the convex wage shift. Starting from a baseline economy calibrated for 1987, I simulate the model under different scenarios characterized by an increased demand for workers with intermediate and higher education. The simulations identify a credit constraints/production complementarities mechanism explaining the convexification: a relaxation of the credit constraints allowed the supply of labour to respond to the increased demand for educated workers, which, because of the complementarity between intermediate and higher educated workers, further increased the relative demand of workers with higher education and therefore their marginal product while it further decreased the relative return of intermediate-educated workers. This mechanism emerges against a number of alternative explanations including different ways of modelling the increased demand for labour.

The results confirm previous findings by Heckman, Lochner and Taber (1998) (HLT) and Lee and Wolpin (2006) (LW) that wage changes are driven by simultaneous movements in the demand and in the supply of workers with different levels of education. However, and importantly, differently from both HLT and LW, education and saving choices are jointly modelled under credit constraints, which affect investment in education and via this returns to schooling.[4]

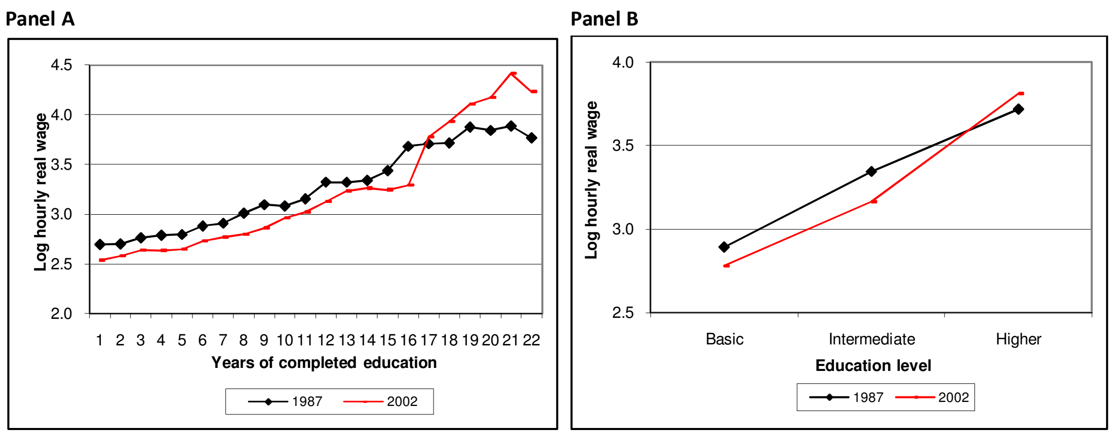
The remainder of the paper is organized as follows. Section 2 documents the wage convexification in Mexico and discusses changes in composition. Section 3 develops and simulates an equilibrium model to assess the relative importance of changes in the demand and in the supply of labour to explain the convexification. Section 4 discusses alternative explanations of the convexification. Section 5 concludes. Appendix A describes the data and the Mexican education system. Appendix B and C discuss the estimation, calibration, and sensitivity analysis of the model.

2 Wage convexification in Mexico

For the analysis of wages I use micro data from the Mexican Employment Survey (*Encuesta Nacional de Empleo Urbano* or ENEU) from 1987 to 2002. The ENEU is the only Mexican household survey continuously available since the late 1980s that collects detailed labour market information and a large array of socioeconomic characteristics; the survey only covers urban areas but, importantly, collects information on both formal and informal workers that in the 1990s accounted for around half of the Mexican labour force (Maloney 2004; and Bosch and Maloney 2006; Binelli and Attanasio 2010). As such, it has been widely used for

[4]Gallipoli, Meghir and Violante (2007) also develop an equilibrium model of savings and educational choices with credit constraints. Their model has a much richer structure than the one developed here.

Figure 1: Convexification of the Mexican wage-education profile. Source: author's calculations based on the Mexican employment survey.



studies of the Mexican labour market, including several recent studies on changes in the wage distribution (e.g. Binelli and Attanasio 2010, Bosch and Manacorda 2010, and Verhoogen 2008).

The sample selection criteria used in this paper follow Binelli and Attanasio (2010): I consider all adult workers aged between 25 and 60 that are actively working at the time of the interview in all municipalities included in each survey year between 1987 and 2002. Wages are measured as real hourly after-tax earnings in the fourth quarter of each year. A brief description of the ENEU survey, further details on the main sample and summary statistics are provided in Appendix A1.

I compute log hourly real wages for three education groups: "basic education", which includes all workers with up to uncompleted intermediate education, "intermediate education", which includes all workers with completed intermediate education and up to uncompleted college, and "higher education", which includes all workers with completed college or more. Details on the Mexican education system and the construction of the education groups are provided in Appendix A2.

Figure 1 presents average log hourly real wages by the number of years of completed education (Panel A) and by education level (Panel B) in the first and in the last year of the sample; Table 1 reports the changes in log wages and in log relative wages graphically shown in Panel B of Figure 1. Panel A shows that in the 1990s mean wages for each year of education below completed college decreased, while they sharply increased for those with completed college education (17 years or more). Panel B and Table 1 show that the divergent trends in bottom and top wages are even more apparent when considering mean wages by level of education rather than by years of completed education: between 1987 and 2002 the college-intermediate log wage gap increased by 73% and the intermediate-basic wage gap decreased by around 15%.[5] The absolute level of wages also changed differentially by increasing at higher education and decreasing at intermediate and basic education: the most substantial loss was at the intermediate level where log hourly real wages fell by 5% (Table 1).

% change ENEU data 1987-2002			
Log wage		Log wage differential	
Basic	−4%		
Intermediate	−5%	Higher-Intermediate	73%
Higher	3%	Intermediate-Basic	−15%

Table 1: Growth of log hourly real wages by level of education and of log relative wages between 1987 and 2002. Source: author's calculations based on the Mexican employment survey.

2.1 Compositional changes to explain the convexification

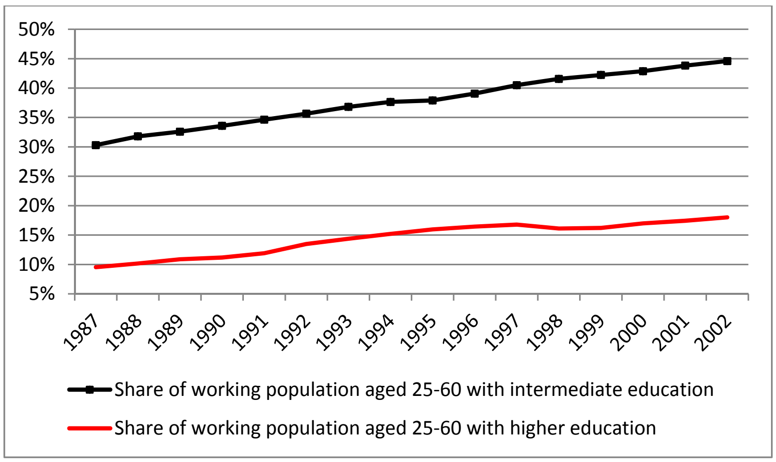
In a study of 16 Latin American countries Behrman, Birdsall and Szekely (2007) document the diverging trend in increasing returns to tertiary education and decreasing returns to secondary education in the 1990s and show that these changes in wage inequality came together with significant changes in labour supply by level of education.[6] Mexico was a leading example: the proportion of the working population aged between 25 and 60 with

[5] Both the difference between mean wages by education in 1987 and 2002 and the changes in the wage differentials are highly statistically significant.

[6] Additionally, unreported results using wage data from the Brazilian and the Colombian national household survey in the 1990s show that wage changes in these two countries were quantitatively very similar to the ones observed in Mexico: in both countries the college-intermediate wage gap increased by aroung 30% while the intermediate-basic wage gap decreased by around 40% in Brazil and by around 22% in Colombia. In addition, as it is the case for Mexico, mean log hourly real wages for those with intermediate decreased by 3% in Brazil and by 2% in Colombia.

intermediate education increased from around 30% in 1987 to 45% 2002, while the proportion of the adult working population with higher education increased from around 10% to 17% in the same years (Figure 2).[7]

Figure 2: Yearly share of working population aged 25-60 with intermediate and higher education. (Source: author's calculations based on the Mexican employment survey.)



The entrance of the new cohorts of educated workers induced compositional changes towards a more educated and relatively younger workforce. Wage profiles tend to be steeper for higher educated and younger workers (e.g. Gosling, Machin and Meghir 1999), thus changes in age composition could have been an important factor contributing to the convex wage shift.

A simple way to investigate the role of changes in age composition is to estimate a standard log wage equation that includes dummies for individuals' level of education (basic, intermediate, and higher), age, and an interaction term between age and education. We can separately estimate this wage equation for 1987 and for 2002, and for each year compute the predicted log wages and log relative wages net of the age effects. We can then calculate the difference in log wages and in log relative wages net of age effects between 1987 and 2002.

[7] Similar patterns characterize the changes in labour supply in Brazil and Colombia. Unreported results using data from the national household surveys of both countries show that the proportion of the adult working population with intermediate education increased from around 32% (Brazil) and 34% (Colombia) in 1987 to around 55% (Brazil) and 43% (Colombia) in 2002. Likewise, the proportion of the adult working population with higher education increased from around 12% (Brazil) and 17% (Colombia) in 1987 to around 14% (Brazil) and 21% (Colombia) in 2002.

Table 2 reports the results in percentage changes with respect to 1987. While the size of the estimated log wage changes is different from the changes in the raw data reported in Table 1, the convexification is evident: the higher-intermediate wage differential increased while the intermediate-basic education wage differential declined.[8]

% change 1987-2002 controlling for age effects			
Log wage		Log wage differential	
Basic	−6%		
Intermediate	−8%	Higher-Intermediate	145%
Higher	−2%	Intermediate-Basic	−44%

Table 2: Growth of log hourly real wages by level of education and of log relative wages between 1987 and 2002 controlling for age and for its interaction with education. Source: author's calculations based on the Mexican employment survey.

% change log relative wages (1987-2002)	Age 25-40 in 2002	Age 41-60 in 2002
Higher versus Intermediate	181%	65%
Intermediate versus Basic	−42%	−62%

Table 3: Growth of log relative wages between 1987 and 2002 controlling for age and for its interaction with education. Source: author's calculations based on the Mexican employment survey.

In addition to changes in age composition, the significant supply increase of workers with intermediate education could have contributed to the convexification via changes in the composition of unobservables, such as workers' ability, by level of education. In particular, a decline in the average ability of intermediate-educated workers due to the expansion of the size of this group could have substantially reduced wages at this level of education and thus driven a convexification of the wage profile.

A preliminary assessment of the contribution of changes in ability composition can be done by comparing the changes in the wage-education profile of the cohorts of workers that made all their education choices before 1987 with the changes in the wage-education profile of the cohorts that invested in education during the 1990s. Assuming that investment in education ends at age 25 and that individuals enter the labour market by the end of the

[8]Unreported results show that the convexification is also apparent when estimating wage regressions that control for age effects for different age subsamples, such as for the subsample of those aged 25-40 or for those aged 41-60 in 2002, as well as when comparing the wage-education profile in 1987 and in 2002 for each of the seven age cohorts in the sample (age 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, and 55-60).

education period, the sub-sample of workers aged 41-60 in 2002 consists of individuals that made all their schooling decisions before 1987, while the sub-sample of workers aged 25-40 in 2002 consists of those that invested in education during the 1990s. If changes in ability composition were driving the convexification, the wage-education profile of those that made all their schooling decisions before 1987 and were in the labour market by then should not have convexified. We can re-estimate the log wage equation that controls for the level of education, age and its interaction with education separately for the sub-sample of those aged 41-60 in 2002 and for the subsample of those aged 25-40 in 2002, and compute the estimated changes in log relative wages with respect to the wage regression estimated for the overall sample in 1987. Table 3 reports the results: as it is apparent, log wages of the 41-60 age sample that made all schooling decisions before 1987 did convexify. Albeit preliminary, this evidence suggests that changes in ability composition did not drive the convexification. The role of ability will be further analyzed within the equilibrium model that we present next.

3 Demand and supply to explain the convexification

The empirical evidence so far suggests that changes in age and ability composition did not drive the convexification. An alternative explanation and one that is consistent with the simultaneous changes in wages and supply by education that are observed in the data is changes in the equilibrium prices of education, that is in the market value of education due to the interplay between the demand and the supply of workers with basic, intermediate and higher education. This explanation is particularly appealing since the supply changes shown in Figure 2 happened in a decade characterized by a significant increase in the demand for labour: all major Latin American countries including Mexico underwent a number of trade liberalization and labour market reforms that increased the demand for skilled labour (Goldberg and Pavcnik 2004, and Winters, McCulloch and McKay 2004).

Changes in education prices could fully explain the convexification or rather explain part of it once changes in age and ability composition have been accounted for. Thus, I develop a model that accounts for both changes in composition and in prices. I do so by considering a standard equilibrium framework where the supply of workers with basic, intermediate and higher education reacts endogenously to changes in labour demand and is modelled in structural details by allowing wages to depend on the equilibrium prices of education, individuals' age and ability.

3.1 The model

3.1.1 Supply side: household decision problem

At each time t the economy consists of overlapping generations of parents and children that live together for four periods, which reproduce the four main education cycles in Mexico: a pre-school period and three periods necessary to complete basic, intermediate and higher education.[9]

Each individual lives for eight periods, four as a child and four as a parent. As a child the individual lives with the parent that works full time and maximizes utility which is a function of joint household consumption. In the first period the child is in pre-school; in the second period the child is sent to compulsory basic education; in the third and fourth period the child can be sent either to school or to work. At the end of the fourth period the parent retires and leaves a bequest of financial assets to the child who starts adult life with the level of education completed during childhood and an amount of assets given by parental bequest.

Labour supply is perfectly inelastic and wages clear the labour markets. The wage of an individual i with education level j and age a in period t is given by:

$$w^i_{j,a,t} = p_{j,t} * \exp(e^i_{j,a,t}) \qquad j = 1, 2, 3 \tag{1}$$

with

$$e^i_{j,a,t} = \eta^i + g_j(age^i_t) + z^i_{j,a,t} \tag{2}$$

where $j = 1, 2, 3$ denotes the education level from basic up to higher education. Wages depend on the price of education, $p_{j,t}$, which is determined as the marginal product of the aggregate supply of education level j in period t, and on labour efficiency, $e^i_{j,a,t}$, which is

[9] For simplicity the length of each period is assumed to be the same and equal to seven years in order to match the average working life of adult Mexican workers of around thirty years. A description of the Mexican schooling system and the construction of the education levels is presented in Appendix A2.

a function of individual's ability endowment, η^i, an education-specific polynomial in age which reflects the growth of wages with experience, $g_j(age_t^i)$, and an education-specific i.i.d. uninsurable shock, $z_{j,a,t}^i$, which is assumed to be normally distributed with mean $\mu_{z_{j,a,t}}$ and variance $\sigma^2_{z_{j,a,t}}$. z captures earnings' volatility and uncertainty, which affected wage changes in Mexico in the 1990s.[10]

Individuals' ability endowment, η^i, represents the permanent component of human capital. It is a measure of ability and all unobservable family background factors that have a permanent impact on human capital. It is assumed to be perfectly transmitted between successive generations: each individual inherits at birth the ability endowment of her parent and passes it over to her own child.[11] The inclusion of ability and education-specific polynomials in age will allow using the model to account for changes in ability and age composition.

In order to solve the household maximization problem the adults (parents) need to form expectations on current and future education prices, which determine wages. Let us define as $p_t(a)$ the vector of current and future education prices forecasted from age a onwards. Omitting for simplicity the t time index, parental maximization problem is given by:

$$V_a(X_a) = \max_{\{c_a, I_a\}_{a=\underline{a}}^{a=\overline{a}}} E\left\{\sum_{a=\underline{a}}^{\overline{a}} \beta^{a-\underline{a}} U(c_a) + \beta^3 \lambda V_{\underline{a}}(X_{\underline{a}})\right\} \tag{3}$$

$$s.t. \quad A_{a+1} = A_a(1+r) + w_{j^P,a} + \left[(1-I_a)w_{j^C,a} - I_a F_{j^C}\right] - c_a \tag{4}$$

$$j_{a+1}^C = \begin{Bmatrix} j_a^C + 1 & if\ I_a = 1 \\ j_a^C & if\ I_a = 0 \end{Bmatrix} \quad \forall\ a = \overline{a}-1, \overline{a} \tag{5}$$

$$A_a \geq -B_a \qquad \forall\ a = \underline{a}, ..., \overline{a}-1 \tag{6}$$

$$A_a \geq 0 \qquad a = \overline{a} \tag{7}$$

[10] Wage volatility characterized the decade of the 1990s in Mexico that was hit by the "Peso crisis" of 1994, which has been identified as an important determinant of changes in wage inequality (Verhoogen 2008).

[11] This is consistent with the empirical evidence from Latin America showing a very high correlation between measured ability of parents and children. As an example, unreported evidence from the Mexican Family Life Survey in 2002 shows that the correlation between Raven test scores of the mother (or father) and their children is above eighty per cent.

where X_a denotes the vector of state variables at age a, which includes the level of adult education, j^P, that is fixed throughout adulthood, the level of child education, j_a^C, the amount of assets at age a, A_a, the vector of current and future skill prices forecasted from age a onwards, $p(a)$, the ability endowment, η, and the idiosyncratic shock to wages, z_a. Then $X_a = (j^P, j_a^C, A_a, p(a), \eta, z_a)$ with j_a^C normalized to zero when consumption is the only choice variable. λ is the degree of parental altruism[12], $\underline{a}$ ($\overline{a}$) denotes the age of the parent at the start (end) of the adult life, and $V_{\underline{a}}(.)$ is the child's lifetime utility once adult.

c_a and A_a denote, respectively, joint household consumption and financial assets at age a. $w_{jP,a}$ is parental wage at age a given parental education level j^P. I_a is an indicator function that equals one if the child is sent to school and zero otherwise. If the child is sent to work, the parent receives the child's wage, $w_{jC,a}$. If the child is sent to school, the parent pays the fixed costs, F_{jC}, for the j^C schooling level attended by the child. E denotes expectations that reflect uncertainty due to the presence of the uninsurable idiosyncratic shocks to earnings. β is the discount factor. The utility function is assumed to be strictly increasing and concave in consumption, so that absolute risk aversion is decreasing in individual's wealth, the impact of risk on investment decisions being higher for poorer than for wealthier households.[13]

The optimization problem described in (3) is solved under four main constraints. The first constraint (equation (4)) is a standard period budget constraint with the term in square brackets switching on when child education becomes a choice variable. The second constraint (equation (5)) defines the law of motion of child's education. The third constraint (equation (6)) is a borrowing restriction imposing a limit B_a on the amount of net indebtedness at age a. The fourth constraint (equation (7)) is a terminal condition that prevents parents from leaving debts to their children.

The borrowing limit, B_a, can take any value between zero, which corresponds to the maximum level of credit constraints of no possible borrowing, and an upper bound that is given by the present discounted value of lifetime earnings at age a under the lowest possible realization of individual labour efficiency, that is under the lowest possible realization of

[12] The assumption of altruistic parents is consistent with the empirical evidence showing that Mexican parents care about their children's utility (Schluter and Wahba 2008).

[13] The utility function is assumed to take a simple CRRA formulation:
$U(c) = \frac{(c)^{1-\gamma}}{1-\gamma}$
where γ is the reciprocal of the intertemporal elasticity of substitution.

the idiosyncratic shock z.[14] The upper bound represents the maximum amount that an individual will always be able to repay without violating the no-debt condition specified in equation (7).[15]

3.1.2 Demand side: aggregate production function

In each year t the representative firm operates a constant returns to scale technology production function over physical and human capital:

$$Y_t = Z_t K_t^{\alpha} HH_t^{1-\alpha} \tag{8}$$

where Y_t denotes aggregate output, K_t is aggregate physical capital and HH_t is aggregate human capital.[16] α denotes the share of physical capital in production which is assumed to be constant over time and Z_t is the technology factor that is normalized to one in all years. I assume that the economy is small and open to the world financial markets.[17] Capital flows in or out of the country so that the marginal product of physical capital equals the world interest rate, r.[18]

HH_t is specified as a nested CES function of the human capital of those with completed basic (H_1), intermediate (H_2) and higher (H_1) education. Instead of assuming perfect substitutability between the three human capitals, I choose a flexible CES specification that allows for different elasticities of substitution (ES) between human capitals'

[14] The empirical distribution of z_j is defined over a finite support with a minimum value, $\underline{z}_j$, and a maximum value, $\overline{z}_j$.

[15] The value of the upper bound arises naturally from the assumption that the utility function satisfies the Inada condition $\lim_{c \to 0} U(c) = -\infty$ and that parents have to repay all debts before retiring.

[16] This specification of the production function assumes that there are no complementarities between physical capital and human capital. This assumption is motivated by the near-constancy of the share of physical capital in production estimated for Latin America in the 1990s (Bosworth, 1998, Harrison, 1996 and Hoffman, 1993).

[17] This assumption is consistent with Mexico being a small economy open to financial trade, particularly with the US. Consistently, the interest rate will be set at the US level.

[18] I assume that there are no adjustment costs for physical and human capital and no shocks to the aggregate production. In the absence of aggregate shocks, the constancy of the world interest rate implies that the economy's physical to human capital ratio is fixed over time, and that firms face no credit constraints. Differently from individual households, firms can freely borrow in the international capital markets at the fixed rate r. There are no financial intermediaries that can borrow money from firms and lend it to households.

pairs[19]:

$$HH_t = [(1-\delta_{s,t})H^{\rho}_{u,t} + \delta_{s,t}H^{\rho}_{s,t}]^{\frac{1}{\rho}} \tag{9}$$

where $H_{u,t}$ is the aggregate human capital for unskilled labour and corresponds to $H_{1,t}$, and $H_{s,t}$ is the aggregate human capital for skilled labour at time t and it is given by the combination of $H_{2,t}$ and $H_{3,t}$:

$$H_{s,t} = [(1-\alpha_{3,t})H^{\theta}_{2,t} + \alpha_{3,t}H^{\theta}_{3,t}]^{\frac{1}{\theta}} \tag{10}$$

The time-varying and education-specific parameters δ and α in equation (9) and (10) denote the shares of the human capital factors in production. Changes in δ and α reflect variations in the productivity and in the demand of the different inputs. The parameter ρ determines the ES between unskilled and skilled labour, which is given by $ES_{u,s} = ES_{1,2} = ES_{1,3} = \frac{1}{1-\rho}$, while θ determines the ES between intermediate and higher education, which is given by $ES_{2,3} = \frac{1}{1-\theta}$.[20] If either ρ or θ is zero, the corresponding nesting is Cobb-Douglas. If $\rho > \theta$, the ES between higher and intermediate is lower than the ES between either higher or intermediate and basic education, which means that there are complementarities in production between workers with intermediate and with higher education.

Labour is measured in efficiency units: each unit of labour is multiplied by the efficiency index defined in equation (2) and the aggregate stock of human capital j in year t, $H_{j,t}$, is given by the sum of the efficiency weighted individual supply of education level j, at time t,

[19]With three human capital inputs there are three ways of nesting them within a CES aggregate: $\widetilde{HH}_1 = \Gamma_1(H_3, \Gamma_2(H_2, H_1))$, $\widetilde{HH}_2 = \Gamma_2(H_2, \Gamma_2(H_3, H_1))$ and $\widetilde{HH}_3 = \Gamma_3(H_1, \Gamma_2(H_2, H_3))$, where Γ_1, Γ_2 and Γ_3 are CES aggregators. The $\widetilde{HH}_3$ nesting is chosen because it imposes a symmetry restriction that does not contrast with the empirical evidence on factor elasticities in Latin America.

In particular, for $\widetilde{HH}_1$ the ES between H_3 and H_1 is restricted to be the same as the ES between H_3 and H_2. For $\widetilde{HH}_2$ the ES between H_2 and H_3 is restricted to be the same as the ES between H_2 and H_1. The restrictions imposed by both $\widetilde{HH}_1$ and $\widetilde{HH}_2$ contrast with factor elasticities previously estimated for Latin America, which show that the ES between higher and intermediate education differs from the one between either higher or intermediate and basic education (Manacorda, Sanchez-Paramo and Schady 2010).

[20]There are different ways of measuring the ES when the aggregate output is produced with more than two inputs. We use the definition of the direct ES. One alternative commonly used definition is the Allen elasticity of substituion. The direct elasticity of substitution between intermediate and higher education is solely a function of the curvature parameter, θ, while the Allen definition involves both the curvature parameter and the factor shares.

$h^j_{i,t}$:

$$H_{j,t} = \sum_i h^j_{i,t} \qquad\qquad j = be, ie, he \tag{11}$$

Differently from physical capital, labour is not internationally mobile and its remuneration is set domestically. Under the assumption of perfectly competitive markets and profit maximization by firms, the price of education level j in year t, $p_{j,t}$, is given by the marginal product of the jth aggregate human capital. By taking the ratios of the marginal products, I can derive the expressions for the relative prices of education:

$$\frac{p_{2,t}}{p_{1,t}} = \frac{\delta_{s,t}}{(1-\delta_{s,t})}(1-\alpha_{3,t})\left(\frac{H_{1,t}}{H_{2,t}}\right)^{1-\rho}\left\{(1-\alpha_{3,t}) + \alpha_{3,t}\left[\frac{H_{3,t}}{H_{2,t}}\right]^{\theta}\right\}^{\frac{\rho-\theta}{\theta}} \tag{12}$$

$$\frac{p_{3,t}}{p_{2,t}} = \frac{\alpha_{3,t}}{(1-\alpha_{3,t})}\left(\frac{H_{3,t}}{H_{2,t}}\right)^{\theta-1} \tag{13}$$

$$\frac{p_{3,t}}{p_{1,t}} = \frac{\delta_{s,t}}{(1-\delta_{s,t})}\alpha_{3,t}\left(\frac{H_{1,t}}{H_{3,t}}\right)^{1-\rho}\left\{\alpha_{3,t} + (1-\alpha_{3,t})\left[\frac{H_{2,t}}{H_{3,t}}\right]^{\theta}\right\}^{\frac{\rho-\theta}{\theta}} \tag{14}$$

The degree of complementarity between intermediate and higher education is an important determinant of the changes in relative prices. An increase in the amount of human capital at intermediate level has a standard supply effect (SE) and a complementarity effect (CE). The standard SE is clear from the human capitals' ratio in round brackets in equation (12) and (13). For a given supply of basic and higher human capital, an increase in H_2 decreases the relative price of intermediate with respect to basic education and increases the relative price of higher with respect to intermediate education. The CE is given by the term in curly brackets in equation (12) and (14). If $\rho > \theta$, that is if higher and intermediate education are more complementary than higher and basic (or intermediate and basic), an increase in H_2 further decreases the relative price of intermediate with respect to basic education and increases the relative price of higher with respect to basic education. The size of the SE and CE effects depends on the magnitude of the elasticity parameters, ρ and θ, which will be directly estimated using micro-data from Mexico (Section 3.2 and B1.2 in

Appendix B).

3.1.3 Equilibrium

Given an initial distribution of ability, financial assets and education and the world interest rate, r, a competitive equilibrium is given by a sequence of vectors of education prices, $p_t = [p_{1,t}, p_{2,t}, p_{3,t}]$, aggregate labour inputs, $H_t = [H_{1,t}, H_{2,t}, H_{3,t}]$, parental decision rules for consumption and education choices, $[c_{a,t}, I_{a,t}]$, individual labour supply of education j, $j_{a,t}$, individual labour efficiency, $e_{j,a,t}$, age, time and education specific measures, $\varphi_{j,a,t}$, for $t = 0, 1, 2, ...$, and $a = \underline{a}, ..., \overline{a}$ such that:

1. Given the prices $[p_{1,t}, p_{2,t}, p_{3,t}]$, the contingent plans $c_{a,t}$ and $I_{a,t}$ solve the household maximization problem (3) subject to (4) to (7).

2. Given the prices $[p_{1,t}, p_{2,t}, p_{3,t}]$, firms choose optimally the production factors and prices are marginal productivities:
$$p_{j,t} = \frac{\partial Y_t}{\partial H_{j,t}} \quad \forall j$$

3. The labour markets clear:
$$H_{j,t} = \sum_{a=\underline{a}}^{a=\overline{a}} \int_S (j_{a,t}(s) * \exp(e_{j,a,t})) d\varphi_{j,a,t}(s) \quad \forall j$$

where S defines the state vector at age a, time t, minus the education states, i.e. $S \equiv (A_{a,t}, p_t(a), \eta, z_{a,t})$.

An equilibrium steady state is a competitive equilibrium with stationary prices and distributions, that is an equilibrium such that $[p_t, H_t] = [p, H]$ for all t. The steady state is computed by solving the model recursively by standard backwards induction from the last to the first period of adult life.[21]

[21] All details of the solution algorithm are available upon request.

3.2 Determining the parameters of the model

There are four main set of parameters to estimate: the parameters of the wage equations (age polynomials, distribution of ability, mean and variance of the wage shock in equation (2)), the parameters of the production function, the preference parameters (discount and intertemporal substitution parameters), the borrowing constraints and the costs of education. The ideal data set to estimate the model would combine micro data on the earnings of workers, their life-cycle consumption and wealth holdings, and macro data on prices and aggregates. Using the micro data joined with aggregate prices, I could estimate the parameters of the household decision problem and construct aggregates of human capital that could be used to determine the output technology. Two obstacles prevent implementing this approach. First, even if individual-level data on wealth and education are available, I lack information on consumption linked to labour earnings over many years. Second, the data on market wages do not reveal education prices, as it is evident from the distinction between w and p in equation (1), so it is not possible to estimate aggregate stocks of human capital using wage data directly.

To circumvent the first limitation, I follow practices widely used in the literature and choose discount and intertemporal substitution parameters in consumption to be consistent with those reported in the empirical literature and that enabled the model to reproduce key features of the macro data like the capital-output ratio. Further, I set B to zero, which corresponds to a the maximum level of credit constraints when no borrowing is allowed and I calibrate each F_j cost of education by matching the share of workers aged between 25 and 60 with the jth level of education in the 1987 ENEU data. I find the costs of intermediate and higher education to be, respectively, around seven and eighteen times the costs of basic education; these relative magnitudes are remarkably close to those that can be computed from available empirical estimates of education costs from micro-data (Section B2 in Appendix B). Importantly, I calibrate all preference and costs of education parametrs after having estimated the wage equations and the production function as well as the initial distribution of wealth and education in 1987, so that the calibrated parameters are consistent with the parameters directly estimated from the data. Further, I explore the sensitivity of the simulations to alternative choices of these parameters. All details on the calibration are given in Section B2 in Appendix B.

To circumvent the second limitation, I follow the standard method of using wage data to infer prices and estimate human capital aggregates developed by Heckman, Lochner and Taber (1998). By having a measure of the human capital series, it is then possible to estimate the production function. The estimation of the wage equations and the production function is discussed in Section B1 in Appendix B. The most important result concerns the production function: I find the elasticity of substitution between workers with higher and with intermediate education being lower than the elasticity of substitution between workers with either higher or intermediate and basic education. Model's simulations will be used to assess the role of these production complementarities to produce the convexification.

3.3 Simulations

Having being solved and estimated, the model can be used to study the factors that induced the wage-education profile to convexify and therefore produced the changes in wages presented in Table 1 by computing the changes in the level of wages by education and in relative wages between different steady state scenarios and a baseline steady state calibrated on the Mexican economy in 1987.

3.3.1 The role of labour demand: production complementarities

I start the analysis of the determinants of the convexification by assessing the contribution of changes in the demand for labour. A substantial empirical literature on Mexico has estimated an increase in the demand for skilled labour in the 1990s[22]; consistently, I also estimate an increase in the share of skilled labour in production (δ_s in equation (9)) of around 1.35% a year (Section B1.2 in Appendix B).

[22]The 1990s in Mexico were a period of significant trade and labour market reforms that changed the structure of production towards the use of skilled labour. The reform effort culminated in 1994 when Mexico became a member of the Organization for Economic Cooperation and Development and entered the North American Free Trade Agreement with the US and Canada. In the same year Mexico was hit by a severe financial crisis, the "Peso crisis", which resulted into a massive devaluation of the national domestic currency. The reform effort and the opening to foreign investment (e.g. Hanson and Harrison 1999) as well as the Peso crisis itself (Verhoogen 2008) resulted into an increase in the use of skilled labour and in the production of skill-intensive goods.

Could the increased demand for skilled workers alone have produced the convexification?

I address this question by comparing the steady state wage-education profile that the model produces under two different counterfactual scenarios. First, I simulate the model by assuming that δ_s increases by 1.35% a year and that the proportions of workers with basic, intermediate and higher education are fixed at the levels observed in Mexico in 1987; in this setting labour supply is taken as exogenously given and all changes in the prices of education are due to changes in the demand for labour. Second, I compare this fixed supply scenario (scenario I) to a second scenario (scenario II) where the supply of labour is allowed to react to the increased demand for skilled labour.

The first column of Table 4 presents the percentage changes of the equilibrium log wages in scenario I with respect to the baseline model; the second column of Table 4 presents the percentage changes in scenario II with respect to scenario I. Table 5 reports the percentage changes in relative wages.

As it is clear from the equilibrium conditions and from the fact that $\delta_u = (1 - \delta_s)$, an increase in δ_s decreases the equilibrium price (and therefore the equilibrium wage) of those with basic education and increases wages at both intermediate and at higher education (column 1 Table 4). With respect to the baseline, both the relative wages to higher and to intermediate education increase (column 1 Table 5).

Scenario II allows the supply of labour to be endogenous and thus simulates the wage changes that the model produces when the prices of education vary to reflect changes in the demand and in the supply of labour. The higher demand for skilled labour increases the returns to intermediate and to higher education and thus gives incentives to invest in education after compulsory schooling. Consistently with the fixed costs of education being lower at intermediate than at higher education ($F_2 < F_3$), the supply of intermediate-educated workers increases more than the one of workers with higher education; with respect to scenario I relative wages to higher education increase while relative wages to intermediate education decline (column 2 Table 5).

The comparison between scenario II and scenario I (column 2 Table 5) shows the role of the endogenous supply of labour: the increased supply of workers with intermediate education depressed the wages at this level of education and triggered a differential change

% change log wage	I vs Baseline	II vs I	III vs II
Basic	−5%	4%	−3%
Intermediate	8%	−7%	3%
Higher	15%	−3%	1%

Table 4: Growth of log wages by education in the four simulation scenarios: scenario I with respect to the baseline (column 1); scenario II with respect to scenario I (column 2); scenario III with respect to scenario II (column 3).

% change log wage differential	I vs Baseline	II vs I	III vs II
Higher versus Intermediate	21%	15%	−8%
Intermediate versus Basic	77%	−33%	28%

Table 5: Growth of log relative wages: scenario I with respect to the baseline (column 1); scenario II with respect to scenario I (column 2); scenario III with respect to scenario II (column 3).

of relative wages, which increase by 15% at higher education, and decreased by 33% at intermediate education. The size of the feedback effects of changes in labour supply on wages depends on the degree of complementarity/substitutability between aggregate human capitals. As already discussed, the estimation of the production function (Section B1.2 in Appendix B) shows that there are complementarities between workers with intermediate and with higher education: the elasticity of substitution (ES) between workers with higher and with intermediate education is estimated to be 4.4, while the ES between workers with either higher or intermediate and basic education is estimated to be 7.1.[23]

The importance of these production complementarities can be quantified by comparing scenario II with a third counterfactual, scenario III, which assumes an isoelastic production function where $ES_{u,s} = ES_{1,2} = ES_{1,3} = ES_{2,3} = \frac{1}{1-\rho} = 4.4$. The third column of Table 4 and Table 5 presents, respectively, the percentage changes in the equilibrium log wages and in the log relative wages in scenario III with respect to scenario II. In the absence of production complementarities, that is when only the direct supply effect operates (Section 3.1.2), the sign of the changes in relative wages is reversed: relative wages to intermediate education increase, and relative wages to higher education decrease (column 3 Table 5).[24]

[23] The values of the estimated elasticities of substitution are much higher than the typical estimates obtained from US data (Katz and Murphy 1992) but they are consistent with the estimates obtained in the only other study that, to the best of my knowledge, has estimated a CES production function with three levels of education for Latin America (Manacorda, Sanchez-Paramo and Schady 2010).

[24] Unreported results show that an isoelastic production function where $\rho = \theta$ and only the direct supply

Clearly, the complementarity effect is important; however, even scenario II is unable to match the convexified wage-education profile observed in the data: by comparing the first and the second column in Table 5 it is clear that both relative returns to intermediate and to higher education increased in scenario II with respect to the baseline economy in 1987. This happens because when borrowing is not allowed too few households have enough resources to invest in intermediate education and therefore allow the supply of intermediate-educated workers to increase enough as to match the drop in intermediate wages that is observed at this level in the data.

3.3.2 The role of labour supply: credit constraints

In the baseline model as well as in the simulations in the previous section, B is set to zero, which corresponds to a situation of no borrowing and maximum credit constraints. In order to assess the role of borrowing, I define a fourth counterfactual, scenario IV, which, as scenario II, allows for endogenous labour supply and complementaries in production, but, differently from scenario II, relaxes the credit constraints to the upper bound that B can take.[25] Table 6 reports the percentage changes in log equilibrium wages and in relative wages in scenario IV with respect to scenario II.

% change scenario IV with respect to scenario II			
Log wage		Log wage differential	
Basic	0%		
Intermediate	−9%	Higher-Intermediate	4%
Higher	−5%	Intermediate-Basic	−42%

Table 6: Growth of log wages by education and of log relative wages in scenario IV with respect to scenario II.

Relative to scenario II, the possibility of borrowing allows more individuals to complete

effect operates would be able to match the convefixied wage-education profile in the data only with an increase in the supply of workers with intermediate education that is twice the size the supply increase observed in the data.

[25] As discussed in section 3.1.1, the internal consistency of the model allows to set an upper bound for the value that B can take at any age, which is given by the present discounted value of the lifetime earnings at age a under the lowest possible realization of the idiosyncratic education-specific shock z_j. Given the distribution of z_j defined over a finite support with a minimum value, $\underline{z}_j$, and a maximum value, $\overline{z}_j$, $\underline{z}_j$ defines the lowest possible value that z_j can take. I compute $\underline{e}^i_{j,a} = \left(\eta^i + g_j(age^i) + \underline{z}_j\right)$. At each age a, given parental education level j, $B_a = \sum_{t=0}^{\overline{a}-a} \frac{w^i_{j,a}}{(1+r)^t} = \sum_{t=0}^{\overline{a}-a} \frac{\left(p_j * \exp(\underline{e}^i_{j,a})\right)}{(1+r)^t}$ where r is the world interest rate.

intermediate and higher education, therefore investment in human capital increases at both levels and the equilibrium wages at intermediate and at higher education decrease. However, because it is more expensive to acquire higher than intermediate education, credit constraints remain binding not allowing all individuals to invest up to higher education; therefore, the supply of intermediate-educated workers increases more than the supply of workers with higher education, so the wage at intermediate decreases more than the wage at higher education (Table 6).

The level of credit constraints appears as the main factor that affects investment in education. If borrowing is not allowed, that is when B is set to zero as in the baseline model, scenarios characterized by changes in the extent of earnings' risk, as well as by changes in additional factors that affect educational investments such as the degree of relative risk aversion and the degree of parental altruism are unable to match the wage changes that are observed in the data (rows six to eight in Table 14 Appendix C).

As expected, there is a positive relationship between the borrowing limit and the size of the increased supply of skilled workers: the more it is possible to borrow, the higher the investment in education after compulsory schooling. Unreported results show that there is a borrowing threshold of around 40% of individuals' lifetime earnings below which the size of the supply increase of those with intermediate education would not be big enough to allow the model to match the wage changes observed in the data.

3.4 Discussion

% change scenario IV with respect to baseline			
Log wage		Log wage differential	
Basic	−1%		
Intermediate	−4%	Higher-Intermediate	51%
Higher	8%	Intermediate-Basic	−15%

Table 7: Growth of log wages by education and of log relative wages in scenario IV with respect to the baseline.

The fit of the model can be assessed by comparing the growth of wages by education and of relative wages computed from the simulations and from the data. In particular, we can compare the changes in wages in scenario IV with respect to the baseline to the changes in wages computed from the data and presented in Table 1. Table 7 presents the growth of log wages and of relative wages in scenario IV with respect to the baseline model. The comparison between Table 7 and Table 1 shows that wage changes in the model are close in magnitude to those in the data. In particular, wages decreased for those with intermediate and basic education, and increased for those with higher education, while relative wages to higher education increased by 73% in the data and by 51% in the model, and relative wages to intermediate education decreased by 15% both in the model and in the data.[26]

The simulations identify a relaxation of credit constraints/production complementarities mechanism explaining the convexification. Is there empirical evidence supporting this mechanism? In particular, is there evidence of production complementaries and increasing access to credit in Mexico in the 1990s?

The production complementarities between workers with intermediate and higher education are consistent with an economy with two main sectors, a first sector that employs low-skilled labour and a second sector where production is carried out by the use of semi and high-skilled labour. This structure of production is a good description of the Mexican economy that can be characterized as comprising of two main sectors: a formal sector of semi and high-skilled workers and an informal sector of low-skilled workers. By defining a worker as "formal" if paying social security contributions in either the private or the public sector, evidence from the ENEU shows that in the 1990s almost 80% of formal sector workers have at least completed high school education. The importance of this dual production structure is consistent with the findings of Binelli and Attanasio (2010) that show how the dynamics of wage inequality in Mexico in the 1990s are strongly correlated with changes in the size of the formal and informal sectors.

The production complementarities channel the effect of the response of the supply of labour to the increased demand thanks to a relaxation of the credit constraints. The simulation results show that a borrowing amount of around 40% of household earnings is needed to match the ENEU data in 2002. How realistic is this finding?

[26] Consistently, the proportions of workers aged 25-60 with basic, intermediate and higher education in the model and in the ENEU data match closely.

The Mexican Expenditure Survey (ENIGH) can be used to relate the change in the level of credit constraints to measurable changes in the credit market. The ENIGH has a similar structure to the Family Expenditure Survey (FES) in the UK. It is available for 1984, 1989, 1992 and every two years since then. Since 1992 the ENIGH survey contains detailed information on a number of variables that can be used to compute measures of financial income and wealth assets (Binelli and Attanasio 2010). A proxy measure for the amount of borrowing as a proportion of household income is the ratio of credit cards debts and consumer loans to household labour income, which can be constrcuted from the ENIGH. Using this measure, evidence from the ENIGH shows that the median ratio of credit cards debts and consumer loans over household labour income increased by around 30% between 1992 and 2002, which is remarkably close to the 40% increase that the model predicts.[27]

In addition to the micro-evidence provided by the ENIGH, there is also macro-evidence that in the 1990s in Mexico borrowing constraints did become less stringent due to a process of financial liberalization and deregulation of the securities markets, which resulted into an increased availability of consumer credit. Evidence from the Bank of Mexico shows that in 2002 the amount of credit to consumers was almost double the size of the amount in 1994.[28]

4 Alternative explanations

Continuing on the model's discussion started in the previous section, this section assesses the robustness of the results to competing explanations of the convex wage shift.

4.1 Multiple demand shocks and task-based technical change

Section 3.3.1 discusses the role of a single demand shock modelled as an increased demand for skilled labour, that is an increase in δ_s (the combined share of intermediate and higher

[27] In particular, ENIGH data show that in 1992 the median value of credit cards debts and consumer loans was at around 551 Mexican Pesos and the median labour income was at around 8,346 Mexican Pesos; in 2002 these amounts increased to, respectively, around 2,073 and 5,698 Mexican Pesos. All results are available upon request.

[28] The most recent available data from the Bank of Mexico show that the steep increase in consumer credit still continues: at the end of the year 2008 the total amount of credit to consumers was almost three times the size of the amount granted in 2002 (http://www.banxico.org.mx/estadisticas/statistics.html).

educated labour), and shows that the model can not produce a convexified wage profile when the supply of education is not allowed to react to the demand increase. However, the results of the estimation of the production function show that in the 1990s both δ_s and α_3 (the share of higher educated labour) increased: δ_s increased by 1.35% a year, and α_3 by around 2.62% a year (Section B1.2 in Appendix B). As it is clear from equations (12) and (13), an increase in α_3 by itself would increase the relative wages to higher education (equation (13)) and decreases the relative wages to intermediate education (equation (12)).

Could an increase in the demand for higher educated labour by itself have produced the convexification? Or, alternatively, could a combination of an increased demand for higher educated labour and an increased demand for skilled labour have produced the convexified wage-education profile?

I answer these questions by simulating the model at constant supply (as in scenario I in Section 3.3.1) and modelling the increase in the demand for labour as an increase in α_3 or rather as a combined increase in α_3 and in δ_s. Rows three and four in Table 14 in Appendix C show the percentage changes in log equilibrium wages and in log relative wages from the initial steady state when α_3 increases by itself (by 1.35% a year) and when it increases in combination with δ_s (α_3 increases by 2.62% a year, δ_s by 1.35% a year). When only α_3 increases, relative wages increase at higher education and decrease at intermediate education but the level of wages increase for all education groups; when both δ_s and α_3 increase, relative wages to intermediate education increase. In both cases, the increase in the level of wages at higher education is 60% higher than what it is observed in the data. Therefore, for the size of the demand changes estimated from the data, neither a single demand shock nor multiple demand shocks alone could not have produced the convexification: the endogenous supply reaction was a fundamental determinant of the convex wage shift.

In the model the effect of the demand shocks on labour supply is driven by the complementarities between workers with higher and with intermediate education. Production complementarities between middle and high-skilled workers have also been pointed out as an important determinant of changes in wage differentials by Autor, Katz and Kearney (2006) (AKK - hereafter). By taking the supply of skills as exogenously given and assuming that middle-skilled workers are more complementary to high than to low-skilled workers and that computerization is a perfect substitute to middle-skilled workers, AKK show that a fall in computer prices displaces middle-skilled workers and leads to a polarization of employment and earnings; US data provide supporting empirical evidence to the qualitative predictions of their model.

The AKK model is an example of the "task-based technical change" (TBTC) models originating from the more nuanced view of skill-biased technological change that introduced the task dimension into the production function (Autor, Levy and Murnane 2003). The key feature of the TBTC models is the assumption that labour production factors (typically three) differ with respect to the task content of their occupations, and that there are substitutabilities between tasks performed by workers with different skills. In other words, the production function is characterized by different degrees of complementarity/substitutability between occupations with different skill intensity so that an increased demand for skilled labour affects not only the supply of skilled labour directly but also the supply of unskilled labour (relative to middle-skilled labour).

TBTC models have been extensively used to explain the polarization of employment and wages (Autor and Dorn 2010 for the US; Goos, Manning and Solomons 2010 for Europe), and to quantify the contribution of changes in employment by occupations to changes in the distribution of wages (Firpo, Fortin and Lemieux 2009 for the US). Even if for Mexico there are no publicly available data with information on the task intensity of occupations, Medina and Posso (2010) apply an AKK-type model to Mexico by assuming a task-distribution by level of education such that low skilled workers perform manual intensive tasks, middle skilled workers perform routine intensive tasks, and highly skilled workers mostly perform abstract tasks. Under this assumed tasks' distribution, they find some evidence of employment and wage polarization in the decade of the 1990s. If tasks data for Mexico were to become available and found to confirm the tasks' distribution assumed by Medina and Posso, their results would suggest that the production complementarities between intermediate and higher educated workers that I estimate using the ENEU data could be driven by complementarities between tasks performed by these two types of educated labour.

4.2 Changes in ability composition

Section 2.1 discusses some preliminary evidence suggesting that the convexification is not driven by changes in ability composition by level of education. We can use the results of the model's simulations to further investigate the role of ability by comparing the changes in wages predicted by the model and presented in Table 7 with the changes in the prices of education, $p_{j,t}$, that is in the component of the wages that does not depend on ability.

Table 8 presents the changes in log prices and in log relative prices computed from the wage changes presented in Table 7, that is the growth of the log education prices and of the relative prices in scenario IV with respect to the baseline model. Both the changes in the level of prices and in relative prices reported in Table 8 are close in magnitude to the wage changes reported in Table 7. In particular, both Tables show a decrease in the level of wages and prices at intermediate education, and a divergent trend in relative wages and prices with the higher-intermediate differential increasing and the intermediate-basic differential decreasing in 2002 with respect to 1987. Interestingly, while the intermediate-basic price differential is lower than the one observed in the data and perfectly matched by the model (15% in Table 1 and Table 7), the higher-intermediate price differential is higher than the wage differential predicted by the model (75% in Table 8 versus 51% in Table 7) and close to the wage differential observed in the data (73% in Table 1), which is consistent with a negative ability sorting at higher education.

% change scenario IV with respect to baseline			
Log price		Log price differential	
Basic	−2%		
Intermediate	−6%	Higher-Intermediate	75%
Higher	10%	Intermediate-Basic	−26%

Table 8: Growth of prices by education and of relative prices in scenario IV with respect to the baseline.

The evidence so far thus shows that changes in ability composition have played a marginal role to explain observed changes in wages. Unfortunately, an important limitation of using model's simulations to assess the role of changes in ability composition is that in the absence of long series of panel data, the robustness of the ability estimates that are used to simulate the model is severely limited by the short length of the panel (Heckman 1981).

More importantly, even if longer series on individual earnings were available, the quantitative importance of the changes in ability composition would remain sensitive to the specific ability distribution estimated from the data: all estimates heavily depend on untestable assumptions on the distribution of the unobservables.

In theory it is of course possible to think of a given initial ability distribution such that a big enough drop in mean ability at intermediate and a big enough increase in mean ability at higher education would produce a convexified wage-education profile. I could simulate the model for an arbitrary change of the moments of this initial ability distribution. However, in the absence of a benchmark value for the changes in ability composition, it is not clear what a meaningful or reasonable change in these moments is. To the best of my knowledge, Binelli, Meghir and Menezes-Filho (2010) (BMM - hereafter) is the only paper that provides an estimate of the changes in ability composition by level of education in a Latin American country. BMM distinguish between four levels of schooling and estimate the changes in ability composition by education and birth cohort during the Brazilian educational expansion of the 1990s.

I use BMM's estimates as a benchmark for the magnitude of the changes in ability composition and perform an indirect robustness test of the quantitative importance of these changes to produce the convexification. Unreported results show that in the absence of changes in the prices of education the mean ability level at intermediate education would have had to decrease five times more than the relative decrease in ability at this level of education that BMM estimate. Thus, with no changes in education prices, the convex wage shift could only have been produced by unrealistically big changes in the composition on ability, which provides further evidence that the convex change in the wage-education profile was not driven by changes in composition.

4.3 Wage setting mechanisms, migration flows and taxation

A final assessment of the model's performance relates to the discussion of three important mechanisms that could have contributed to the sustained low level of wages at basic education and via this to the decrease in the relative wages to intermediate education. First, the model abstracts from wage setting mechanisms and institutions such as the minimum wage that have been found to be important factors driving changes in wages in Mexico as well as in the US.[29] It could be that binding minimum wages prevented the wages of low skilled workers to fall thus driving the decrease in the relative wages to intermediate education. However, the empirical evidence for Mexico rules out this possibility: the data show that in the 1990s minimum wages were not binding and rather decreased substantially (Bosch and Manacorda 2010). In particular, the drop in mean wages at basic education was much smaller than the one of the minimum wages: between 1987 and 2002 minimum wages declined by around 50% relative to median earnings (Bosch and Manacorda 2010), while the evidence in Table 1 shows that wages at basic education decreased by 1% less than wages at intermediate education.

Second, an issue that deserves some discussion is the role of taxation. The use of after-tax wages to study the convexification could be problematic in the presence of changes in the tax system that affected tax progressivity. In particular, a decrease in tax progressivity could have increased after-tax wages more at the top than at the bottom of the distribution. In the 1980s and 1990s Mexico underwent significant changes in the taxation system: in the 1980s the marginal taxation rate decreased from 55 to 35, while it increased back to 40 in the 1990s that were characterized by a series of tax reforms that increased tax credits and exemptions for low-income earners favouring incomes at the bottom of the income distribution.[30] These changes in taxation could have contributed to the sustained value of wages at basic education but there is no evidence of a decrease in progressivity that did benefit after-tax wages at the top of the distribution.

A similar conclusion can be drawn for migration, which is a third factor from which the model abstracts. In the 1990s there were vast migration flows from Mexico to the US. However, the Mexico-US migration was mainly an outflow of low-skilled workers with two thirds of the adult Mexican immigrants having not completed intermediate education.[31] This low-skilled migration could have contributed to reduce the fall in the wage at basic education

[29] Bosch and Manacorda (2010) find that the deterioration of the real minimum wage in Mexico in the 1990s was an important determinant of changes in wage inequality. Lemieux (2007) finds that changes in labor market institutions can account for around a third of the changes in low-end and top-end wage inequality in the US in the 1990s.

[30] http://www.taxpolicycenter.org/taxfacts/

[31] Report of the US Center for Immigration Studies for 2001 available at www.cis.org.

but there is no evidence that it did affect the middle and the top of the wage distributions. An interesting topic worth further study would be to disentangle the downward pressure on wages due to the decrease in the relative demand for workers with basic education and the upper pressure due to the migration of this type of workers to the US.

5 Conclusion

This paper studies a central feature that characterizes the changes in wage inequality in the decade of the 1990s: the wage-education profile convexified. The wage differential between higher and intermediate education increased and the wage differential between intermediate and basic education declined. These wage changes have important implications for the process of human capital accumulation. The non-linearity of the wage profile changes the opportunity costs of investing in education, which becomes profitable only if college education is completed. This may induce the poor to drop out of school or even not to invest in human capital at all if they cannot afford financing education until the end of college.

In Mexico the wage changes were particularly pronounced and came together with significant changes in the demand and in the supply of educated labour. This paper shows that the simultaneous changes in the demand and the supply of labour were a fundamental determinant of the convexification that can be explained by a two-way interaction between these demand and supply changes: an initial increase in the demand for workers with intermediate and higher education induced a supply reaction with non-linear effects on wages due to complementaries in production between these two types of workers. The supply reaction happened because of increased availability of credit to finance investments in education. Thus, an important implication of the empirical analysis is that easier access to credit has led to higher wage inequality due to an erosion of the return to intermediate wages, which is a finding that is worth further investigation by comparing the wage inequality consequences of increased resources to finance education in countries at different levels of development. This is left for future research.

References

[1] Anderson, Edward, Paul J. G. Tang, and Adrian Wood. 2006. "Globalization, Co-operation Costs and Wage Inequalities." *Oxford Economic Papers*, 58: 569-595.

[2] Arrau, Patricio, and Sweder van Wijnbergen. 1991. "Intertemporal Substitution, Risk Aversion and Private Savings in Mexico." The World Bank Working Paper Series 682.

[3] Autor, David H., and David Dorn. 2010 "The Growth of Low Skill Service Jobs and the Polarization of the U.S. labour Market." http://econ-www.mit.edu/faculty/dautor/papers

[4] Autor, David H., Lawrence F. Katz, and Melissa S. Kearney. 2006. "The Polarization of the U.S. labour Market." *American Economic Review*, 96: 198-194.

[5] Autor, David H., Frank Levy, and Richard J. Murnane. 2003. "The Skill Content of Recent Technological Change: An Empirical Exploration." *Quarterly Journal of Economics*, 118(4): 1279-1334.

[6] Avalos, Antonio, and Andreas Savvides. 2003. "On the Determinants of the Wage Differential in Latin America and East Asia: Openness, Technology Transfer and labour Supply." LABEA Working Paper No. 19.

[7] Behrman, Jere, Nancy Birdsall, and Miguel Szekely. 2007. "Economic Policy Changes and Wage Differentials in Latin America." *Economic Development and Cultural Change*, 56(1): 57-98.

[8] Binelli, Chiara, and Orazio Attanasio. 2010. "Mexico in the 1990s: the Main Cross-Sectional Facts." *Review of Economic Dynamics*, Vol. 13(1): 1-14.

[9] Binelli, Chiara, Costas Meghir, and Naercio Menezes-Filho. 2010. "Educational Attainment and Wages in Brazil." Unpublished.

[10] Blom, Andreas, Holm-Nielsen Lauritz, and Verner Dorte. 2001. "Education, Earnings and Inequality in Brazil, 1982-1998." Policy Research Working Paper No. 2686. Washington, DC: World Bank.

[11] Bosch, Mariano, and Marco Manacorda. 2010. "Minimum Wages and Earnings Inequality in Urban Mexico." *American Economic Journal: Applied Economics*, Vol. 2: 128-149.

[12] Bosch, Mariano, and William F. Maloney. 2006. "Gross Worker Flows in the Presence of Informal labour Markets: The Mexican Experience 1987–2002." The World Bank, Washington, DC.

[13] Bosworth, Barry. 1998. "Productivity Growth in Mexico." http://www.brookings.edu/papers/1998/07_mexico_bosworth.aspx

[14] Bouillon, Cesar, Arianna Legovini, and Nora Lustig. 2005. "Can Education Explain Changes in Income Inequality in Mexico?" In *The Microeconomics of Income Distribution Dynamics in East Asia and Latin America*, ed. Francois Bourguignon, Francisco H. G. Ferreira, and Nora Lustig. Washington DC: The World Bank.

[15] Deschênes, Olivier. 2002. "Unobserved Ability, Comparative Advantage and the Rising Return to Education in the United States: A Cohort-Based Approach." http://www.econ.ucsb.edu/~olivier/research.html.

[16] Firpo Sergio, Nicole Fortin, and Thomas Lemieux. 2009. "Occupational Tasks and Changes in the Wage Structure." http://federation.ens.fr/ydepot/semin/texte0910/LEM2010OCC.pdf

[17] Gallipoli, Giovanni, Costas Meghir, and Gianluca Violante. 2008. "Equilibrium Effects of Education Policies: a Quantitative Evaluation." Unpublished.

[18] Goldberg, Pinelopi K., and Nina Pavcnik. 2004. "Trade, Inequality, and Poverty: What Do I Know? Evidence from Recent Trade Liberalization Episodes in Developing Countries." *Brookings Trade Forum* 2004, Washington DC: Brookings Institute.

[19] Goldin, Claudia, and Lawrence F. Katz. 2007. "Long-Run Changes in the Wage Structure: Narrowing, Widening, Polarizing." Brookings Papers on Economic Activity 2.

[20] Goos, Maarten, and Alan Manning. 2003. "Lousy and Lovely Jobs: The Rising Polarization of Work in Britain." CEP Discussion Paper 640.

[21] Goos, Maarten, Alan Manning, and Anna Salomons. 2010. "Explaining Job Polarization in Europe: The Roles of Technology, Globalization and Institutions." CEP Discussion Paper No 1026.

[22] Gosling, Amanda, Sthephen Machin and Costas Meghir (2000), 'The changing distribution of male wages in the UK.' *Review of Economic Studies*, 67(6): 35-66.

[23] Hanson, Gordon and Ann Harrison. 1999. "Trade Liberalization and Wage Inequality in Mexico." *Industrial and labour Relations Review*, 52(2): 271-288.

[24] Harrison, Ann. 1996. "Openness and Growth: A Time Series, Cross-Country Analysis for Developing Countries." *Journal of Developing Economics*, 48: 419-47.

[25] Heckman J. James. 1981. "The Incidental Parameters Problem and the Problem of Initial Condition in Estimating a Discrete Time-Discrete Data Stochastic Process." In *Structural Analysis of Discrete Data and Econometric Applications*, ed. Charles F. Manski and Daniel L. McFadden. Cambridge: The MIT Press.

[26] Heckman, James J., Lance Lochner, and Christopher Taber.1998. "Explaining Raising Wage Inequality: Explorations with a Dynamic General Equilibrium Model of labour Earnings with Heterogeneous Agents." *Review of Economic Dynamics*, 1:1-58.

[27] Hernández, Mercedes, Adolfo Chávez , and Hector Bourges. 1987. "Valor nutritivo de los alimentos mexicanos. Tablas de uso práctico." Publication L-12 10^a edition, Mexico. Instituto Nacional de Nutricion INN.

[28] Hoffman, Andre'. 1993. "Economic Development in Latin America in the 20th Century: A Comparative Perspective." In Explaining Economic Growth, ed. Adam Szirmai, Bart van Ark, and Dirk Pilat. New York: North Holland.

[29] Katz, Lawrence F., and Kevin M. Murphy K. 1992. "Changes in Relative Wages, 1963-1987: Supply and Demand Factors." *Quarterly Journal of Economics*, 107(1): 35-78.

[30] Lee, Donghoon, and Kenneth Wolpin. 2006. "Accounting for Wage and Employment Changes in the U.S. from 1968-2000: A Dynamic Model of labour Market Equilibrium." PIER Working Paper 06-005.

[31] Lemieux, Thomas. 2006. "Post-secondary Education and Increasing Wage Inequality." *American Economic Review*, Papers and Proceedings 96(2): 195-199.

[32] Lemieux, Thomas. 2007. "The Changing Nature of Wage Inequality." http://www.econ.ubc.ca/lemieux/recent.htm.

[33] Liu, Amy Y. C. 2006. "Changing Wage Structure and Education in Vietnam, 1992-1998." *Economics of Transitions*, 14(4): 681–706.

[34] Lopez Boo, Florencia. 2008. "The Evolution of Returns to Schooling in Argentina." Unpublished.

[35] Maloney, Willian F. 2004. "Informality revisited." *World Development* 32 (7), 1159–1178.

[36] Manacorda, Marco, Carolina Sanchez-Paramo, and Norbert R. Schady. 2010. "Changes in Returns to Education in Latin America: The Role of Demand and Supply of Skills." *Industrial and labour Relations Review*, 63(2): 307-326.

[37] Medina Carlos A., and Christian M. Posso. 2010. "Technical Change and Polarization of the labour Market: Evidence for Colombia, Brazil and Mexico." *Borradores de ECONOMIA*, Num. 614: 1-51.

[38] Mehta, Aashish, Jesus Felipe, Pilipinas Quising, and Shiela Camingue. 2007. "Changing Patterns in Mincerian Returns to Education and Employment Structure in Three Asian Countries." Paper 06. Santa Barbara, CA: Institute for Social, Behavioral, and Economic Research, Center for Global Studies, University of California.

[39] Mookherjee, Dilip, and Debraj Ray. 2010. "Inequality and Markets: Some Implications of Occupational Diversity." *American Economic Journal Microeconomics*, 2(4): 38-76.

[40] Schady, Norbert R. 2001. "Convexity and Sheepskin Effects in the Human Capital Earnings Function. Recent Evidence for Filipino Men." World Bank Policy Research Working Paper 2566.

[41] Schluter, Christian and Jackline Wahba. 2008. "Are parents altruistic? Evidence from Mexico", *Journal of Population Economics*, 23, (3), 1153-1174.

[42] Söderbom, Mans, Francis Teal, Anthony Wambugu, and Godius Kahyarara. 2006. "The Dynamics of Returns to Education in Kenyan and Tanzanian Manufacturing manufacturing." *Oxford Bulletin of Economics and Statistics*, 68(3): 261-288.

[43] Verhoogen, Eric A. 2008. "Trade, Quality Upgrading and Wage Inequality in the Mexican Manufacturing Sector." *Quarterly Journal of Economics,* 123(2): 489-530.

[44] Winters, Alan, Neil McCulloch, and Andrew McKay. 2004. "Trade Liberalization and Poverty: the Evidence So Far." *Journal of Economic Literature*, 62: 72-115.

[45] Wood, Adrian. 2002. "Globalization and Wage Inequalities: A Synthesis of Three Theories." *Weltwirtschaftliches Archiv*, 138: 54-82.

Appendix A - The ENEU and the Mexican education system

A1 The Mexican employment survey (ENEU)

The ENEU (*Encuesta Nacional de Empleo Urbano*) is the Mexican employment survey collected yearly by the Mexican national statistical office, INEGI. It is a quarterly household survey with a rotating panel structure similar to the US Current Population Survey: households are interviewed for five consecutive quarters and in each quarter 20% of the households are replaced by new households that are interviewed for the first time. The survey reports detailed employment information on individuals at least twelve years old with several questions on occupation status, type and characteristics of employment, sector of main and secondary job, contract type, number of working hours, monthly earnings, unemployment status and duration, and social security taxes paid by the worker's employer in the private and public sector.

The ENEU is available yearly from 1987 to 2004. The survey covers only urban areas with municipalities being the primary sampling units. The sampling scheme has changed over time as a number of smaller municipalities have progressively entered the sample. The sample selection criteria follow Binelli and Attanasio (2010): the main sample includes all individuals aged between 25 and 60 that are actively working at the time of the interview in all municipalities included in each survey year between 1987 and 2002.

Table 9 reports summary statistics for the main variables used in the empirical analysis. The definition of earnings refers to monthly earnings received in the fourth quarter of each year from the main job net of all labour taxes and social security contributions paid in either public or private funds. For those paid by the week the survey transforms weekly earnings into monthly earnings by multiplying the former by 4.3. Similar adjustments are used for workers paid by the day or every two weeks. Hourly wages are computed as the ratio between monthly earnings and hours worked in the main occupation last month. The wage distribution has been trimmed to exclude 22 observations for which hourly real wages were equal to or exceeded 3000 Mexican Pesos. All wage data are adjusted for inflation by using the Mexican national CPI of June 2002.

Variable	Obs	Mean	Std. Dev.	Min	Max
Age	1798179	38.87	8.93	25	60
Level of education	1798179	1.60	0.81	1	3
Year	1798179	1996	4.26	1987	2002
Hourly real wage	1798179	28.12	33.10	0.01	2986.48

Table 9: Summary statistics ENEU sample.

A2 The Mexican education system and construction of the education groups

The Mexican education system consists of four main cycles: pre-school, primary, secondary (lower and upper) and post-secondary education. Pre-school education is between age 3 and 6 and is provided free of charge. Since 2004 one year of pre-school education has became mandatory. Primary education starts at age 6, lasts six years and has always been compulsory. Secondary education comprises two main levels: lower and upper secondary. Lower secondary lasts between three to four years, depending on the program. Upper secondary lasts three years. Both levels of secondary education includes an "academic" and a "vocational" branch that paves the way, respectively, to university and non-university education. In 1993 lower secondary education became compulsory. This policy change mainly affected rural areas with a large increase in the construction of schools and corresponding increasing attainment rates at lower secondary education in these areas. Post-secondary education comprises universities, 2 and 4-years technical institutes, and graduate education. By far the majority of undergraduate students are enrolled in universities and a very small proportion is enrolled in 2-years technical institutes. University takes 4 to 5 years and graduate education lasts between 2 to 4 years (2 years are necessary to obtain a Master degree and two additional years to obtain a PhD).

In order to construct the three education groups used in this paper, the schooling levels have been aggregated as follows: the "basic education" group includes all individuals that have up to uncompleted upper secondary education, the "intermediate education" group includes all individuals that have up to uncompleted university education, and the "higher education" group includes all individuals with completed university education or more. In the decade of the 1990s average attainment rates were above 90% at primary education nationwide; at lower secondary they were above 80% in urban areas and below 40% in rural areas. Since the ENEU only covers urban areas motivates the choice of grouping primary and lower secondary into compulsory basic education. Finally, as in Manacorda, Sanchez-Paramo and Schady (2010), I aggregate the academic and vocational branch of secondary education by considering in the "intermediate" group all individuals that have completed any of the two branches.

Appendix B - Estimation and calibration

B1 Estimation

1. Wage equations

The ideal dataset to estimate the wage equations and the structure of the error term would have been a panel data set with individual information on wages, a measure of permanent heterogeneity with a measurable impact on wages, such as individual test scores, and age, spanning over many years. However, for Mexico there are no available data sets that follow individuals over many years.[32] Also, until 2004 there were no standardized measures of test scores.[33] The only available data set with information on wages and a panel dimension following individuals over the 1990s is the ENEU, which follows individuals over the four quarters of a given year (Appendix A).

I exploit the ENEU quarterly panel structure by specifying the following log wage equation for individual i with education level j in quarter qr:

$$\ln w^i_{j,qr} = \ln w_{j,qr} + g_j(age^i_{qr}) + u^i_{j,qr} \qquad j = 1, 2, 3 \tag{15}$$

$$u^i_{j,qr} = \eta^i + z^i_{j,qr} \tag{16}$$

$$z_{j,qr} \sim N(0, \sigma^2_{z_{j,qr}}) \tag{17}$$

[32] The first survey that collects individual information on wages in Mexico over many years is the Mexican Family Life Survey (MxFLS). The first wave of the MxFLS was collected in 2002 and it was followed by a second wave in 2005; two additional waves are scheduled for 2009 and 2012. At present only the first two waves are available.

[33] Non-standardized test scores were collected in Mexico since 1998 (*Estandares Nacionales*). In 2001 the ENLACE (*ENgaging LAtino Communities for Education*) initiative was launched to support Latino students to progress from primary to secondary and college education. Standardized test scores started to be collected as part of ENLACE in 2004.

where $\ln w^i_{j,qr}$ is the log hourly real wage of individual i with education level j in quarter qr. $\ln w_{j,qr}$ is the mean log wage among those with education level j in quarter qr, $g_j(.)$ is an education-specific quadratic polynomial in age that proxies for experience in the labour market, η^i is a permanent individual-specific effect, and z is an i.i.d. shock.

The estimates of the wage equations are used to parametrize wages of the working population that in the model includes both adult (parents) and young (children) workers. Therefore, I consider all wage workers between the age of 15 (minimum legal working age) and 60 (average retirement age) and I construct panels of individuals by matching workers by the position in an identified household, number of years of education and age. For each year between 1987 and 2002 I run the following fixed effects regression:

$$(\ln w^i_{j,qr} - \ln \overline{w}^i_j) = (\ln w_{j,qr} - \ln \overline{w}_j) + g_j(age^i_{qr}) - g_j\overline{(age^i)} + (u^i_{j,qr} - \overline{u}^i_j) \tag{18}$$

where the upper-bar variables denote time averages over the four quarters in a given year. $\ln \overline{w}^i_j$ is the average log wage over the four quarters for the ith individual with the jth education level, $\ln \overline{w}_j$ is the mean log wage over the four quarters for education level j. The term $(\ln w_{j,qr} - \ln \overline{w}_j)$ is modelled as quarter-education dummies' interactions. $g_j(age^i_{qr})$ is an education-specific quadratic polynomial in age.

For the purposes of the model's simulations I require the unconditional distribution of ability, which can be estimated as follows:

$$\widehat{\eta}_i = \frac{\sum_{n=1}^{N(i)} \ln w^i_{qr} - \widehat{\ln w_{qr}} - g\widehat{(age^i_{qr})}}{N(i)} \tag{19}$$

where $N(i)$ is the total number of observations available on individual i. In any given year the estimated fixed-effects give an estimate of the distribution of η for the population working in that year. Figure 3 presents the estimated distribution of η for 1987. I use the first and second moment of this distribution to parametrize the ability distribution before the wage convexification took place. I estimate a variance of 0.25 and a zero mean.[34]

[34] In the model the distribution of ability is assumed to be time-invariant since ability is perfectly transmitted between generations. The model therefore abstract from any heterogeneity in ability endownments between successive cohorts active in the labour market in different years.

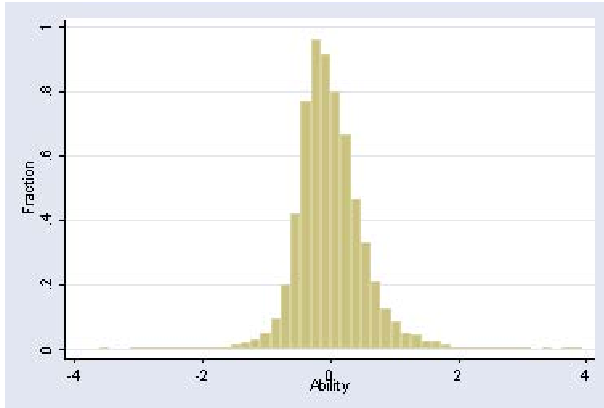


Figure 3: Estimation of the wage equations: ability distribution in 1987 (Source: author's calculations based on the 1987 ENEU survey)

Given the estimation of equation (18), I can treat as observable the following:

$$z^i_{j,qr} = \ln w^i_{j,qr} - g_j(age^i_{qr}) - \ln w_{j,qr} - \eta^i \qquad (20)$$

I assume that $z_{j,qr}$ is a normally distributed i.i.d. shock with mean zero and variance $\sigma^2_{z_j}$, which I use to parametrize the distribution of z for each education group and year between 1987 and 2002. Table 10 presents the estimated variances $\sigma^2_{z_j}$ by education and year. The coefficients of the quadratic polynomials $g_j(age^i_{qr})$ provide the estimates of the education-specific and year-specific experience effects. Table 11 presents the (yearly rescaled) estimates of the age and age squared term by education and year.

Year	Basic	Intermediate	Higher
1987	0.065	0.070	0.079
1988	0.065	0.074	0.088
1989	0.070	0.077	0.117
1990	0.068	0.084	0.119
1991	0.069	0.087	0.113
1992	0.069	0.083	0.106
1993	0.065	0.083	0.113
1994	0.070	0.084	0.115
1995	0.073	0.085	0.110
1996	0.068	0.083	0.111
1997	0.064	0.078	0.099
1998	0.066	0.083	0.099
1999	0.078	0.094	0.121
2000	0.078	0.094	0.125
2001	0.063	0.076	0.099
2002	0.071	0.089	0.114

Table 10: Estimation of the wage equations: variance of the residuals (Source: author's calculations based on the 1987-2002 ENEU survey)

Year	Basic		Intermediate		Higher	
	age	age squared	age	age squared	age	age squared
1987	0.098	-0.005	0.122	-0.004	0.274	-0.012
1988	0.079	-0.004	0.188	-0.008	0.302	-0.014
1989	0.092	-0.005	0.194	-0.010	0.320	-0.015
1990	0.116	-0.006	0.167	-0.007	0.303	-0.013
1991	0.118	-0.006	0.102	-0.004	0.264	-0.011
1992	0.096	-0.005	0.279	-0.013	0.224	-0.010
1993	0.121	-0.006	0.170	-0.006	0.204	-0.009
1994	0.168	-0.009	0.257	-0.010	0.184	-0.007
1995	0.171	-0.008	0.253	-0.011	0.216	-0.008
1996	0.161	-0.008	0.166	-0.006	0.243	-0.009
1997	0.108	-0.005	0.236	-0.010	0.281	-0.012
1998	0.104	-0.005	0.106	-0.003	0.182	-0.006
1999	0.131	-0.007	0.131	-0.005	0.228	-0.010
2000	0.118	-0.006	0.162	-0.006	0.253	-0.010
2001	0.108	-0.006	0.104	-0.003	0.186	-0.007
2002	0.124	-0.006	0.129	-0.005	0.196	-0.007

Table 11: Estimation of the wage equations: age polynomials (Source: author's calculations based on the 1987-2002 ENEU survey)

2. Production function

The method used to approximate the aggregate human capital series follows Heckman, Lochner and Taber (1998) by obtaining the estimated value of human capital j at time t, $\widehat{H}_{j,t}$, as the ratio of the total wage bill for education level j in year t, and an estimate of the price for that level of education in that year, $\widehat{p}_{j,t}$.

I obtain an estimate of the log prices by level of education and year by running the fixed effect regression specified in equation (18) for each year between 1987 and 2002 and computing the predicted mean log hourly real wage by level of education net of the individual fixed effects. In order to compute the wage bills I use the Mexican Expenditure Survey, the ENIGH (*Encuesta Nacional de Ingresos y Gastos de los Hogares*), that is nationally-representative and reports individual earnings together with detailed information on assets and consumption. The ENIGH is available in 1984, 1987 and every two years since then. For each year between 1987 and 2002 and education group I compute the wage bill by summing over the individual earnings of all primary wage earners aged between 15 and 60. I linearly interpolate the available data for the missing years.

Given the wage bills and the (log) education prices, I divide the wage bills by the exponentiated value of the log price of education to obtain the time series of the human capital aggregates for each year and education group. The identification of the H factors is then consistent with the ability distribution estimated from the data and used to simulate the model.[35] Log linearizing equation (13) in Section 3.1.2 and rewriting it in terms of wage bills I obtain:

$$(\log WB_{3,t} - \log WB_{2,t}) = [\log \alpha_{3,t} - \log(1-\alpha_{3,t})] + \theta(\log \widehat{H}_{3,t} - \log \widehat{H}_{2,t}) \qquad (21)$$

where $\widehat{H}_{3,t}$ and $\widehat{H}_{2,t}$ denote the estimated higher and intermediate human capital aggregate at time t. The time-varying factor shares $\alpha_{2,t}$ and $\alpha_{3,t}$ reflect changes in the productivity of and in the demand for workers with intermediate and higher education. I express the log of the share parameters as the sum of a constant and a time-varying component:

$$\log \alpha_{j,t} = \phi_{0,j} + \phi_{1,j} * t + e_{j,t} \qquad (22)$$

where $\phi_{0,j}$ is an education-specific constant, t denotes a linear time trend and $e_{j,t}$ is a normally distributed i.i.d. shock at time t for education level j.

Combining equation (21) and (22), the value of the parameter determining the elasticity of substitution between higher and intermediate education, θ, can be estimated from a regression of the ratio of the log wage bills on the ratio of the human capital aggregates, a linear trend and a constant. Then, a measure of skilled human capital can be constructed as a weighted sum of workers with intermediate and higher education. To do so, I need an estimate of the log factor shares $\alpha_{3,t}$. Given equation (21) and (22) and the fact that $\alpha_{2,t} = (1-\alpha_{3,t})$, I have that $\log\left[\frac{\alpha_{3,t}}{(1-\alpha_{3,t})}\right] = (\beta_0 + \beta_1 * t)$, where $\beta_0 = (\phi_{0,3} - \phi_{0,2})$ and $\beta_1 = (\phi_{1,3} - \phi_{1,2})$. Therefore, $\alpha_{3,t} = \frac{\exp(\beta_0+\beta_1 * t)}{(1+\exp(\beta_0+\beta_1 * t))}$. Finally, I can estimate a regression of the ratio of the log wage bills for skilled and unskilled on the ratio of skilled and unskilled human capital, a linear trend and a constant to obtain an estimate of ρ.[36]

[35] Heckman, Lochner and Taber (1998) assume that at older ages changes in wages are solely due to changes in education prices and do not depend any more on ability. Therefore, they use the average wages by year and level of education for the workers aged 45 or more to derive an estimate of the time series of education prices. By following the same procedure and using the mean log wages by education for the workers aged 45 or more in each ENEU wave, the main results of the estimation of the production function remain unchanged.

[36] Using the wage bill equations for skilled and unskilled, the equivalent of equation (22) for $\log \delta_{s,t}$ and the definition of the unskilled labor share as one minus the skilled share, I can identify $\delta_{s,t}$ following the same steps used to identify $\alpha_{3,t}$. For the year 1987, I obtain a baseline estimate of 0.55 for α_3 and of 0.69 for δ_s.

Equation (21) suffers from endogeneity: changes in the relative supply of education react to the changes in relative demand that this equation is set to identify. I instrument $(\log \widehat{H}_{3,t} - \log \widehat{H}_{2,t})$ with the lagged values of the human capital stocks themselves and with the size of the cohorts of workers with compulsory basic education measured as the proportion of those with primary education in a given year.

The first instrument is a standard instrumental variable often used in macroeconomics to estimate production functions (e.g. Heckman, Lochner and Taber, 1998; Gallipoli, Meghir and Violante 2008). The assumption is that lagged relative supply impacts on relative wages only via current relative supply, the validity of which increases with longer time series. With sixteen years of data (1987-2002) I can experiment with the use of different sets of lags. The second instrument is motivated by the very nature of the model: primary education is compulsory so it is not a margin of choice. At the same time, it clearly impacts on educational investments at both intermediate and at higher education by determining the level of the price of basic education and therefore the relative returns to intermediate as well as to higher education.

Table 12 reports the estimates of the elasticity of substitution between higher and intermediate education: the first, second and third column report, respectively, the second-stage and the first-stage results when using as instrumental variable the first lag of the log human capital difference (IVa), the size of the cohorts of workers with primary education (IVb), and both of them (IVc, where the first row of the first-stage results reports the first-stage estimate of the lagged human capital difference, and the second row reports the first-stage estimate of the size of the cohorts of workers with primary education). Table 13 reports the estimates of the elasticity of substitution between skilled and unskilled: the second-stage results, and the first-stage results when using as instrument the first lag of the log human capital difference.[37] All instruments in the first stage have a strong significant impact on the endogenous variable and in the expected direction.

There are two sets of important parameters' estimates in Tables 12 and 13: the time trends and the implied elasticity of substitution (ES). The time trends' estimates mean that

[37] The size of the primary educated cohorts is not valid in this case since it is a linear function of the denominator of the endogenous variable to be instrumented.

	Higher versus Intermediate		
Parameter	IVa	IVb	IVc
Difference log H	0.7726	0.7331	0.7239
	(0.0636)	(0.0556)	(0.0583)
Time trend	0.0262	0.0279	0.0287
	(0.0048)	(0.0041)	(0.0049)
Constant	−51.9469	−55.2268	−56.8015
	(9.5317)	(8.2465)	(9.7303)
Implied ES	4.4	3.7	3.6
	First Stage		
Instruments' set	0.5796	−6.4816	0.2184
	(0.1822)	(1.5061)	(0.1753)
			−6.2105
			(2.3588)

Table 12: Estimation of the elasticity of substitution between workers with higher and with intermediate education. IVa: instrument is first lagged difference of higher and intermediate human capital. IVb: instrument is the size of the primary educated cohort. IVc: instruments are both first lagged difference of higher and intermediate human capital and size of the primary educated cohort. Standard errors in parenthesis.

between 1987 and 2002 the demand for higher educated and for skilled workers increased, respectively, by around 2.7% and 1.35% a year. This finding is consistent with the results of an extensive previous literature that has estimated a significant increase of the demand for skilled labour in Mexico in the mid 1990s (e. g. Hanson and Harrison 1999). The ES between workers with higher and with intermediate education, which can be directly obtained from the estimate of θ in Table 12, is lower than the ES between workers with either higher (or intermediate) and with basic education, which is consistent with the presence of complementarities in production between workers with intermediate and with higher education.

I assess the robustness of the estimation results by running two specification tests of the production function. First, a joint estimation of the system of equations to test for the equality of the coefficients of the log relative supply of higher and intermediate and skilled and unskilled labour: the test gives a value of chi-squared of 7.1 with a P-value of 0.0077 confirming that ρ and θ are statistically significantly different. Second, a test for the assumption of equality between $ES_{3,1}$ and $ES_{2,1}$, which is a restriction imposed by the

Parameter	*Skilled versus Unskilled*
Difference log H	0.8601
	(0.1362)
Time trend	0.0135
	(0.0065)
Constant	−26.0616
	(13.0620)
Implied ES	7.1
	First Stage
Lagged difference log H	0.8327
	(0.1512)

Table 13: Estimation of the elasticity of substitution between skilled and unskilled workers. Instrument is first lagged difference of skilled and unskilled human capital. Standard errors in parenthesis. "Unskilled" are workers with basic education. "Skilled" is the sum of workers with intermediate and with higher education.

symmetry of the CES operator: the test returns a value of chi-squared of 0.35 with a P-value of 0.5525, therefore not being able to reject the null hypothesis of equal coefficients.

B2 Calibration

1. Initial distribution of wealth and education, preferences, credit constraints and costs of schooling

I set the initial distribution of education of the adult and the young to match the education distributions observed in the 1987 ENEU data. Consistently with the OLG model's assumptions, I define the "adult workers' population" in the ENEU as the one made by all working heads of households aged between 25 and 60 with basic, intermediate and higher education, and the "young workers' population" as the one made by all workers living with their parents, aged between 15 and 24, and that have completed basic and intermediate education. I compute the education distribution of the adult workers as the relative proportions of adult workers with basic, intermediate and higher education in 1987, and the education distribution of the young workers as the relative proportion of those with basic and intermediate education among the young.

The fixed costs of schooling by level of education are set to match the education distribution of the adult in 1987. I find $F_1 = 0.035$, $F_2 = 0.26$ and $F_3 = 0.64$, which implies that the costs of intermediate education are around seven times the costs of basic education and the costs of higher education are around eighteen times the costs of basic education. The F_j fixed costs in the model measure the average total direct costs of education, which include fees, costs of school material and maintenance. An empirical counterpart of these costs is provided by the first wave of the Mexican Family Life Survey (MxFLS), which collects high quality data on a rich set of variables for a cross section of Mexican households in 2002. The MxFLS contains a detailed set of questions on education costs and distinguishes between tuition fees, costs of exams, books, school material, uniforms and maintenance costs for public and private schools. Summing over all these different costs' categories and averaging the costs over public and private education, the costs of intermediate education are around eight times the ones at primary while the costs at higher education are around nineteen times the ones at primary, which are relative magnitudes that are remarkably close to the ones obtained from the model's calibration.[38]

The ENEU survey does not include information on wealth and consumption, which are instead provided by the ENIGH. I set the initial wealth distribution to a lognormal distribution with mean and standard deviation computed from the distribution of financial assets of the workers aged between 25 and 60 in the ENIGH 1992.[39] The coefficient of relative risk aversion, γ, is set to 0.9, which gives a value of around 1.1 for the elasticity of intertemporal substitution (EIS), which is taken from Arrau and van Wijnbergen (1991) that estimate for Mexico an EIS between a lower bound of 0.8 and an upper bound of 1.4. Consumption is adjusted to account for the presence of the child. I use an equivalence scale of 0.7 for a child, which reflects the average calories intake of a child relative to an adult as reported by the Mexican National Nutritional Institute (Hernández, Chávez and Bourges, 1987). Assuming that parent-child dynasties are linked by fully altruistic preferences, the altruism parameter, λ, is set to one. The limit on net indebtedness, B, is set to zero, which corresponds to the maximum level of credit constraints.

[38]The model abstracts from the non-pecuniary or inderect costs of education. Despite being informative for policy inference, the distinction between direct and indirect costs of schooling is not key to the arguments developed in this paper.

[39]The ENIGH reached its final structure only in 1992 with significant changes in the questionnaire and data collection in the years before. For this reason, the wealth distribution is parametrized using the moments of the 1992 distribution. Importantly, the results of the simulations are robust to matching additional moments of the wealth distribution.

2. Interest rate and capital share

The model assumes a small open economy and the value of the real interest rate, r, is set to a US benchmark value. I choose a value of 5%, which is the average real interest rate on the US 6-months Treasury Bills published by the Federal Reserve Board for the period between 1990 and 2000.

Given an average working life of the adult Mexican population of approximately thirty years, the model period is set to 7 years. Therefore, the interest rate in the model is $r = (1.05^7 - 1) \cong 0.41$. Setting the yearly discount factor equal to the inverse of $(1 + r)$, $\beta = 1.05^{-7} \cong 0.71$. The capital share, α, is set to 0.35, which is the average value between the lower and the upper bound estimate for Latin American countries.[40]

Appendix C - Sensitivity analysis

	Log wages			Log relative wages	
Simulated economy	Basic	Intermediate	Higher	Higher-Int	Int-Basic
1. Data	-4%	-5%	3%	73%	-15%
2. Scenario IV	-1%	-4%	8%	51%	-15%
3. Increase alpha	7%	4%	61%	210%	-22%
4. Increase alpha and delta	-6%	-4%	63%	258%	14%
5. Borrowing limit equals costs higher education	11%	-2%	2%	16%	-80%
6. Increase earnings risk	3%	18%	22%	-3%	80%
7. Higher risk aversion	3%	15%	22%	13%	62%
8. Lower parental altruism	-6%	18%	45%	83%	135%

Table 14: Percentage change log wages by education and log relative wages with respect to baseline model in 1987.

Notes:

1. Percentage difference in log wages and log relative wages from 1987 to 2002 in ENEU data.
2. Increased demand for skilled labour and relaxation credit constraints to maximum possible borrowing. All details in Section 5.2.
3. Increase demand for higher educated labour and no borrowing. All other parameters as in Scenario IV.
4. Increased demand for skilled labour and for higher educated labour and no borrowing. All other parameters as in Scenario IV.
5. Reduced credit constraints: max borrowing equals fixed costs higher education. All other parameters as in Scenario IV.
6. Highest variance shocks to earnings by education from Table 5 and no borrowing. All other parameters as in Scenario IV.
7. Higher degree relative risk aversion (γ=1.25) and no borrowing. All other parameters as in Scenario IV.
8. Lower degree of parental altruism (λ=0.8) and no borrowing. All other parameters as in Scenario IV.

Table 14 presents the percentage changes between 1987 and 2002 in log wages by education and log relative wages estimated from the ENEU data (row one), and simulated from the

[40] Bosworth (1998) for a discussion of the empirical issues involved in the estimation of the capital share in Mexico and Harrison (1996) and Hoffman (1993) for two cross-countries empirical studies that use a capital share that varies between the value of 0.3 and 0.4 for a group of Latin American countries.

equilibrium model in different scenarios with respect to the baseline. Row two reports the results from Scenario IV, which are discussed in Section 3.3. Rows three and four report the simulation results of alternative ways of modelling the demand for skill, which are discussed in Section 4.1.

Rows five to eight report the results for changes in parameters that directly affect education and savings' choices. Row five presents the results for the case when the maximum amount that is possible to borrow equals the fixed costs of higher education. With respect to the baseline model and consistently with the increased availability of borrowing, investment in basic education decreases, and the supply of workers with intermediate and with higher education increases. As in scenario IV, wages convexify: relative wages of workers with higher education increase, and relative wages of workers with intermediate education declined. Interestingly, investment in intermediate education in this scenario increases less than in scenario IV. When it is possible to borrow an amount that covers the fixed costs of higher education, the relaxation of the credit constraints is big enough to allow more individuals to finance education up to the highest level so that investment in education increases less at intermediate and more at the higher level, thus log wages at intermediate decrease less (2% versus 4%) and log wages at higher education increase less (2% versus 8%) than in scenario IV; consistently, the higher-intermediate wage differential increases much less (16% versus 73%) and the intermediate-basic wage differential decreases much more (80% versus 15%) than in scenario IV.

Rows six to eight show the results of changes in the extent of earnings risk, in the degree of relative risk aversion, and in the degree of parental altruism, which are all important determinants of how much parents invest in children's education. The extent of earnings risk in the model depends on the variance of the idiosyncratic shocks to wages, z. An increase in earnings' risk affects both the ability to pay for the fixed costs of education, and the expected profitability of educational investments by making returns to schooling more volatile. Rows six reports the percentage changes in log wages by education and in log relative wages when the variance of earnings for each education level is set at the maximum value estimated from the data for that level of education between 1987 and 2002 and reported in Table 10. Rows seven shows the simulation results when the degree of relative risk aversion is such that the elasticity of intertemporal substitution equals, respectively, the lower bound estimated for Mexico by Arrau and van Wijnbergen (1991). Row eight presents the results obtained when the degree of parental altruism decreases from the baseline value of 1 to a value of 0.8.

When earnings' risk increases, parents substitute children's education with work: investment at both intermediate and at higher education decreases with the size of the decrease being bigger at higher education, thus the higher-intermediate wage differential decreases. A higher degree of relative risk aversion (row seven) has a similar negative effect on educational investments, even if in this case the lower investment at intermediate education is smaller in size, and thus the higher-intermediate wage differential increases. A lower parental altruism also results into reduced educational investments after compulsory schooling with the most sizable reduction at the higher education level; consistently, row 8 shows that in this scenario wages at both intermediate and higher education increase, especially at higher education (by 45%) so that both the intermediate-basic and the higher-intermediate wage differential increase substantially. Overall, only the two scenarios characterized by an increase in borrowing and thus a relaxation of the credit constraints (scenario IV and the scenario in row 5) match both the decrease in log wages at intermediate, and the divergent trend in decreasing intermediate-basic and increasing higher-intermediate wage differentials.