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THE DEMAND - SUPPLY - DEMAND TWIST: HOW THE WAGE STRUCTURE GOT MORE CONVEX

The Demand-Supply-Demand Twist: How the Wage Structure Got More Convex*

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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 both sorts of educated workers stimulated a supply response; the increased supply of intermediate-educated 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, Latin America.

JEL Codes: J23, J24, J31, C68.

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1 Introduction

The changes in wage inequality observed in the 1990s in many countries have 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.[1] Inequality between education groups has also grown faster in the top half than in the bottom half of the distribution. Starting from a linear relationship between log earnings and the number of years of completed education, the wage profile convexified, with the returns to college education rising sharply and the returns to intermediate levels of education decreasing or remaining largely unchanged. This pattern has been documented both for the US and for a number of developing countries.[2]

Efforts to explain this pattern up to now have focused on the US, where the changes in relative wages were much smaller than in any of the other countries where the convexification has been documented.[3] The main suggested explanation has been increasing returns to college in a model where the supply of education is taken as given and there are heterogeneous returns to schooling (Deschenes, 2002 and Lemieux, 2006). The reason of this rise in the returns to college as opposed to other observed and unobserved measures of skills remains un-understood.

This paper suggests a different (though not necessarily inconsistent) explanation for the observed convexification. The argument is based on a two-way interaction between the demand and the supply of education. An initial increase in the demand of workers with intermediate and college education increased the returns to both these two types of educated

[1]See Goos and Manning (2003) for the UK, Autor, Katz and Kearney (2006) and Goldin and Katz (2007) for the US, Spitz-Oener (2006) for West Germany, Binelli and Attanasio (2009) for Mexico. More generally, mounting evidence suggests that the growth in wage inequality observed in the 1990s in many countries has been increasingly concentrated at the top end of the wage distribution (Feenberg and Poterba, 2000 and Piketty and Saez, 2003 for the US, Atkinson, 2002 for the UK, Banerjee and Piketty, 2005 for India, and Piketty, 2005 for France).

[2]See Deschenes (2002) and Lemieux (2006, 2007) for the US, Schady (2001) for the Philippines, Bouillon, Legovini and Lustig (2005) for Mexico, Söderbom, Teal, Wambugu and Kahyarara (2006) for Kenya and Tanzania, Liu (2007) for Vietnam, and Lopez Boo (2008) for Argentina.

[3]Using data from the US Current Population Survey Lemieux (2007) show that between 1989 and 1999 the high school graduates-high school dropouts wag gap barely changed while the college-high school wage gap increased by around six per cent for males and seven per cent for females. Consistently with these small changes in relative wages, the changes in the relative supply of workers with high school and college education have also been modest (Goldin and Katz, 2007).

workers and therefore gave incentives to invest in human capital. The increased supply of intermediate-educated workers further increased the demand for college-educated workers (and therefore the returns to college) since intermediate and college-educated workers are complementary in production. As a result, the returns to college increased and the returns to intermediate education declined. The increase of the supply of intermediate-educated workers can be explained with a relaxation of the credit constraints to the supply of human capital, which in turn determined the extent of the convexification.

An empirical innovation of this paper is to study the causes of convexification in a place where it was far more pronounced than in the US, namely Latin America. Between 1987 and 2002 in Brazil, Colombia and Mexico, which together accounted for over seventy per cent of the region's GDP, the higher (college or more)-intermediate (high school) wage differential increased on average by more than forty-five per cent and the intermediate-basic (compulsory education) wage differential declined by over twenty-five per cent. The mean wage at intermediate level fell absolutely. These changes in wages were accompanied by significant changes in the supply of education. Compulsory education became almost universal and the proportion of people who completed high school increased from around 32 to 48 per cent.[4] The proportion of college graduates went from an average of 13 per cent in 1987 to an average of 18 per cent in 2002.[5]

These supply changes could in theory have caused the convexification by altering the composition of intermediate-educated workers, and in particular by a decline in the average ability of these workers due to the expansion of the size of this group. However, I show that this was not the case in Mexico, for either observable (such as cohort, sector of employment and work experience) or unobservable (ability or quality of the workers) characteristics. Then, I develop a model to quantify the importance of the changes in the prices of education as the proximate cause of the convex shift. The education prices are the market value of completing a given education level independently of any (observable and unobservable)

[4] In the year 1987 the proportion of the adult population with completed secondary education was 32 per cent in Brazil, 34 per cent in Colombia and 30 per cent in Mexico. In the year 2002 these proportions increased, respectively, to 55, 43, 45 per cent.

[5] In the year 1987 the proportion of college graduates among the adult population was around 12 per cent in Brazil, 17 per cent in Colombia and 10 per cent in Mexico. In the year 2002 these proportions increased to, respectively, 14, 21 and 17 per cent.

individual characteristic and they change as a result of movements in the demand and in the supply of education.

The setting is an incomplete market, dynamic model of savings and educational choices where the interest rate is taken as given and the education prices are the marginal productivities of three human capital aggregates - basic, intermediate and higher education - that build up the economy human capital endowment. Education (and savings) choices are taken by altruistic parents that face credit constraints. Individual wages are a function of the level of education, an insurable i.i.d. shock and an endowment of ability that is received at birth and is perfectly transmitted across generations. The key model feature is embedded in the production function that is modelled as a flexible CES which allows for different elasticities of substitution between human capital's pairs.

I estimate the wage equations and the production function using micro data from Mexico between 1987 and 2002 and I calibrate the rest of the parameters. The key result of the estimation concerns the production function. I find that the substitution elasticities are consistent with the complementarity between intermediate and higher education. I also find that the demand for skilled labor increased by an average of 1.35 per cent a year, which confirms the findings of an extensive empirical literature that found an increased demand for skilled labour in Latin America in the 1990s (Goldberg and Pavcnik, 2004 and Winters, McCulloch and McKay, 2004, Manacorda, Sanchez-Paramo and Schady, 2006).

I use the economy calibrated in 1987 as the baseline model and I solve for the steady state skill prices. Then, I take the increased demand for skilled labor as the exogenous shock and I compute the equilibrium skill prices under different scenarios characterized by this increased demand for skilled labor and different levels of credit constraints.

The simulations show the mechanism at work: first, in the presence of complementarities between workers with intermediate and higher education, in addition to the standard supply effect the growth of the supply of intermediate education increases the relative demand for higher education and therefore its marginal product while it decreases the relative return of intermediate with respect to basic education; second, the drop of the level of the wage at intermediate is due to a relaxation of the credit constraints on the supply of human capital: the availability of borrowing to pay for the costs of education determines the extent of the supply increase at intermediate and therefore the size of the drop in the wage at this level. The model is able to reproduce the main facts that characterize the growth of both the relative wages and the level of wages by education observed in Mexico in the 1990s.

The results confirm the findings of Heckman, Lochner and Taber (1998) and Lee and Wolpin (2006) that the feedback impact of changes in the supply of skills on their prices is an important determinant of the evolution of wage inequality. What this paper adds is showing that accounting for the equilibrium effects of changes in the prices and supply of education is crucial to explain not only the changes in the relative wages but also in the level of wages. And, in doing so, the framework proposed here is able to identify the main mechanisms that drive these changes. In this regard, the inclusion of savings under credit constraints is an important difference with respect to both Heckman, Lochner and Taber (1998) and Lee and Wolpin (2006) and a crucial model feature to explain the evolution of wage inequality.[6]

The mechanism proposed here identifies the complementarities between workers with intermediate and higher education as a fundamental determinant of the convex shift. A recent contribution by Autor, Katz and Kearney (2006) (AKK - hereafter) does also point at production complementarities between middle and high-skilled workers as an important determinant of changes in wage inequality. In their model AKK take the supply of skills as exogenously given and use US data to provide some supporting empirical evidence to the qualitative predictions of the model.[7] Differently from AKK this paper allows the supply of skills to react to the changes in the wage returns and the model is brought to the data for a quantitative assessment of how much the complementarities can explain of the observed changes in the wage differentials.

Finally, the results of this paper provide an empirical test of the long run theory of

[6]A paper that develops an equilibrium model of savings and educational choices with credit constraints is Gallipoli, Meghir and Violante (2007). The model of Gallipoli et al. has a much richer structure than the one developed here and it does address a very different question: they study the long run effects of policy interventions on educational choices and the distribution of earnings. The change in wage inequality associated with a particular policy is an outcome measure to assess the performance of an education policy.

[7]In their model computerization represents the exogenous shock that they assume to be a perfect substitute to middle-skilled workers. Assuming that middle-skilled workers are more complementary to high than to low-skilled, a fall in computer prices displaces middle-skilled workers and leads to a polarization of employment and earnings. The authors themselves recognize that endogenous skill responses could offset some of the impacts of computer price's decline on wage inequality.

equilibrium wage functions developed by Mookherjee and Ray (2008). In an equilibrium model of savings and occupational choices, they derive the theoretical prediction of a convex relationship between the skill-intensity of an occupation and its marginal rate of return, which has broad implications concerning the role of the markets in generating persistent inequality.

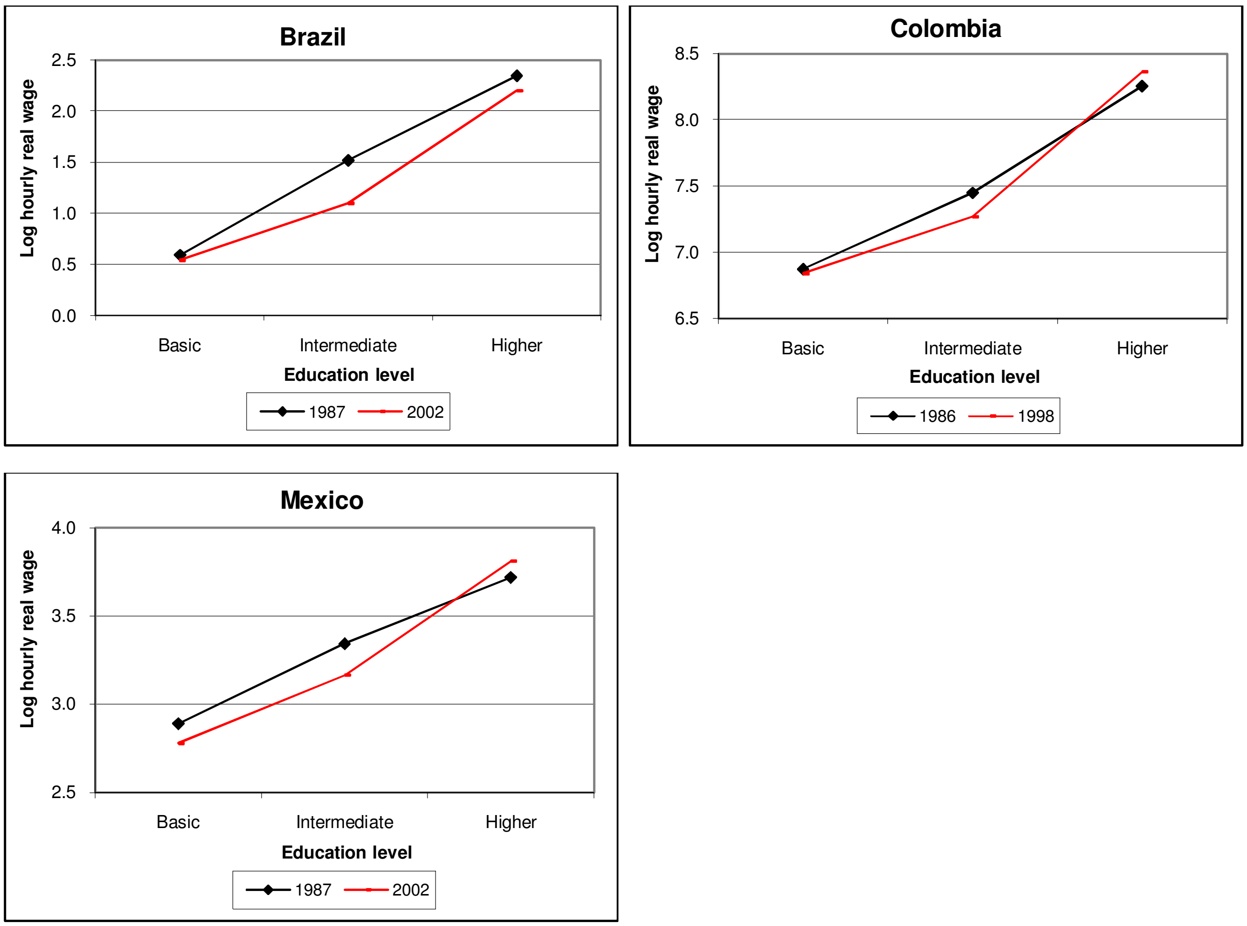
The remainder of the paper is organized as follows. Section 2 presents some empirical evidence on changes in wage inequality in Latin America in the 1990s. Section 3 presents the model and defines the equilibrium. Section 4 discusses the estimation and calibration of the model. Section 5 presents the main results from the simulations. Section 6 discusses the model's assessment. Section 7 gives some concluding remarks. Appendix A describes the main dataset used in the empirical analysis. Appendix B gives details of the method used to solve the model. Appendix C presents the results of the model's estimation and calibration.

2 Wage convexification in Latin America

Figure 1 presents the mean log hourly real wage in Brazil, Colombia and Mexico at the end of the 1980s and in 2002. In each of the three countries the convexification is apparent: in the 1990s wages have become a more convex function of the level of education.[8] The wage premium to higher education is substantial: in 2002 it is over one hundred per cent in Brazil and Colombia and around sixty-five per cent in Mexico. In addition, the premium has been rising over time, with an increase of around thirty per cent in Brazil and Colombia and of over seventy per cent in Mexico. At the same time intermediate graduates have lost ground. From a value of around ninety-three per cent in Brazil and fifty-five and forty-five per cent in Colombia and Mexico at the end of the 1980s, by the year 2002 relative wages at intermediate with respect to basic education decreased by around forty per cent in Brazil and twenty-two and fifteen per cent in Colombia and Mexico. The double change in the relative wages that characterizes the convexification was driven by a drop in the level of the

[8]The convexity of the wage profile changes the typical concave shape of the wage functions in Latin America in the 1970s and 1980s, which were characterized by decreasing returns to higher education (Patrinos and Psacharopoulos, 2004).

Figure 1: Convexification of the Wage Profile in Latin America (Source: author's calculations based on the national household survey for Brazil and Colombia and the employment survey for Mexico. Adult population aged 25-60. Basic education is up to uncompleted secondary, intermediate education is up to uncompleted college, and higher education is at least completed college.)



wage at intermediate that fell below the value at the end of the 1980s. Between 1987 and 2002 the mean wage at intermediate education decreased in real terms by three and two per cent in Brazil and Colombia and by as much as five per cent in Mexico.[9]

Surprisingly, the empirical literature on Latin America so far has focused on the increase in the premium to college rather than on the convexification and has explained this rise in

[9]For each of the three countries the difference of the mean real wages by education between the two years is highly statistically significant. A test of the increase of the relative wage at higher education and the decline of the relative wage at intermediate education also returns highly significant results.

the returns to college with changes either in the supply or in the demand for skills.[10] On the contrary, this paper focuses on the convexification and the results will show the importance of investigating the role of the interactions between the demand and the supply of education to explain it.

A first possibility is that the convex shift was due to changes in the composition of observable or unobservable characteristics of the cohorts that entered the labor market in the 1990s. As for observables, the estimation of wage equations that control for labor market experience, gender, sector of employment and their interaction with the level of education show that the wage profiles are qualitatively very similar to the ones reported in Figure 1.[11] As for unobservables, changes in the ability composition of the education groups and in particular a decline in the average ability of intermediate-educated workers as a result of the expansion of the size of this group could have reduced the wage at this level of education substantially and made the wage profile convexified. The next section discusses this possibility.

2.1 Preliminary evidence of changes in prices versus ability

There are two preliminary ways to assess the importance of changes in ability to explain changes in observed wages. First, we can compare the evolution of the relative returns to education for the cohorts of graduates that made their education choices before 1987 with the relative returns of those cohorts that invested in education during the 1990s. The graphs in Figure 1 report the mean log hourly real wages for all individuals aged between 25 and 60. Assuming that investment in education ends at age 25 and that the individuals enter into the labor market at the end of the education period if not before, we can divide the 25-60 age sample in two groups. The first group is made up by the individuals that made all their schooling decisions before 1987, that is by all individuals that are older than forty in 2002; the second group is made up by those that are between 25 and 40 years old in 2002. If changes

[10] One exception is Robbins (1996) who applies the approach developed by Katz and Murphy (1992) to analyze the changes in the relative wages and in the relative supply of education for a number of Latin American countries. However, he only consideres two education groups - skilled and unskilled workers - once more focusing exclusively on the changes in the wage premium to higher education.

[11] All results are available from the author upon request.

in ability composition at intermediate and higher education are driving the convexification, the wage profile of those that made all their schooling decisions before 1987 and were in the labor market by then should not have convexified during the 1990s. Unreported results show that in 2002 the wage profile convexified for both age groups: changes in ability composition do not seem to be driving the convexification.

Second, we can look at changes in relative wages within the same birth cohort. If changes in relative wages are explained by changes in the ability composition due to the entrance of new cohorts in the labor market, there should be no changes in relative wages within a given birth cohort. If there are changes and they follow a pattern similar to the ones observed between cohorts, then changes in wages must be a reflection of changes in the relative prices of skills rather than changes in the ability of workers with different levels of education. Unreported results show that the convexification of the wage profile observed in the 1990s in the sample that includes many cohorts as plotted in Figure 1 is the same as the one found when considering the mean wages by level of education at the beginning and at the end of the 1990s for a given birth cohort.

All empirical evidence discussed so far suggests that the convexification was not driven by changes in the composition of individuals' observable or unobservable characteristics.[12] Therefore, changes in the prices of education, that is in the component of the observed wages that is independent of any individual characteristic, appear as an appealing explanation of the convexification. The rest of the paper will develop a model to quantify the importance of the changes in the prices of education to explain the convex shift. The model has two key features: (1) educational and saving choices are jointly made under credit constraints on the supply of human capital; (2) the production function allows for different degrees of substitutability/complementarity between aggregate human capitals.

[12] This confirms the findings of Jacoby and Skoufias (2002) for Mexico and Binelli, Meghir and Menezes-Filho (2009) for Brazil that changes in ability composition can only account for part of the increase in the observed college premium.

3 The model

At each time t the economy consists of overlapping generations of parents and children that live together for four periods: a pre-school period and three periods necessary to complete the three education levels - basic, intermediate and higher education. At $t = 1$ each cohort schooling and wealth distribution are taken as exogenous initial conditions. From $t = 2$ these distributions evolve endogenously as a result of parental maximizing behavior.

3.1 Supply side: household decision problem

A continuum of individuals is born at each time t. 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 two periods consumption is the only choice variable. In the first period the child is in pre-school, in the second period is sent to compulsory basic education. In the third and fourth period the child can be sent either to school or to work. If the child is sent to school, the parent has to pay a fixed cost that is education-specific. If sent to work, the child works full time and gives her earnings to the parent. At the end of the fourth period the parent retires and leaves a bequest of financial assets to the child. The child starts the adult life with the level of education completed during childhood and an amount of assets given by parental bequest.

Labor supply is perfectly inelastic and wages clear the labor 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. $p_{j,t}$ is the price of a unit of human capital of type j at time t; it is determined as the marginal product of the aggregate supply of education level j in period t. $e^i_{j,a,t}$ denotes labor efficiency of individual i, which is a function of η^i, the individual's ability endowment, $g_j(age_t^i)$, an education-specific polynomial in age which reflects the growth of wages with experience, and $z^i_{j,a,t}$, an education-specific i.i.d. uninsurable shock that is assumed to be normally distributed with mean $\mu_{z_{j,a,t}}$ and variance $\sigma^2_{z_{j,a,t}}$. The uninsurable shock is received in each period and is a proxy of earnings' volatility and uncertainty.

The individual's 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 formation. 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.[13]

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

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

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

$$j^C_{a+1} = \begin{Bmatrix} j^C_a + 1 & if\ I_a = 1 \\ j^C_a & if\ I_a = 0 \end{Bmatrix} \quad \forall\ a = \overline{a}-1, \overline{a} \tag{5}$$

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

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

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^C_a,

[13] The assumption of perfect transmissibility of ability from parents to children is motivated by the empirical evidence from Latin America. The correlation between proxies for the ability level of parents and children is high. As an example, data from the Mexican Family Life Survey in 2002 shows that the correlation between the Raven test of the mother (or father) and their children is above eighty per cent.

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, $\underline{a}$ ($\overline{a}$) denotes the age of the parent at 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 taking the value of one when 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, z. 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.[14]

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 dying in debt: they can not leave 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 labor efficiency, that is under the lowest possible realization of the idiosyncratic shock z.[15] The upper bound represents the maximum amount that an

[14] We assume that the utility function takes a simple CRRA formulation:
$U(c) = \frac{(c)^{1-\gamma}}{1-\gamma}$
where γ is the reciprocal of the intertemporal elasticity of substitution.

[15] The empirical distribution of z_j is defined over a finite support with a minimum value, $\underline{z}_j$, and a maximum value, $\overline{z}_j$. Therefore, wages are assumed to be always positive and different from zero.

individual will always be able to repay without violating the no-debt condition specified in equation (7).[16]

3.2 Demand side: aggregate production function

The representative firm operates a constant returns to scale technology over physical and human capital. I assume that there are no adjustment costs for physical and human capital and no shocks to the aggregate production. The production function in year t is given by:

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

where Y_t denotes aggregate output, K_t is aggregate physical capital and HH_t is aggregate human capital.[17] 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.[18] I assume that the economy is small and open to the world financial markets. Capital flows in or out of the country so that the marginal product of physical capital equals the world interest rate, r.[19]

I consider three types of human capital corresponding to the three education levels that the individuals can complete and I specify the aggregate human capital in year t, HH_t, as a nested CES function over the three types of human capital, H_1, H_2, H_3, which represent, respectively, the human capital of those completing basic, intermediate and higher education.

The choice of how to combine the three human capital inputs in the HH aggregate determines the elasticity of substitution (ES) between the H factors, which drives the direction

[16] 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.

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

[18] Given the assumption of no population growth and the normalization of Z, there is no growth in steady state. Growth in the model will only occur during the transition towards a steady state as a result of the reallocation of efficiency units of labor from less to more productive combinations of the different types of human capital.

[19] 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. Also, this assumtion implies that firms face no credit constraints. Differently from individual households, they 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.

and the magnitude of the equilibrium effects. I choose a flexible specification for the aggregate human capital that allows for different elasticities of substitution (ES) between human capitals' pairs. A convenient way to allow for a different ES between pairs of human capital is to combine them within a CES specification. I use the CES specification because it is simple, has few parameters and restricts the substitution elasticities to be constant.[20]

Given 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 CES functional form imposes symmetry restrictions on substitution elasticities. For $\widetilde{HH}_1$, the ES between H_3 and H_1 is restricted to be the same as the one 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 one between H_2 and H_1. These restrictions contrast with factor elasticities previously estimated for LACs which show that the ES between higher and intermediate education differs from the one between either higher or intermediate and basic education.[21] Therefore, HH_t is specified as it follows:

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

where $H_{u,t}$ and $H_{s,t}$ are, respectively, the human capital aggregate for unskilled and skilled labour at time t.

$H_{u,t}$ corresponds to $H_{1,t}$ and H_s is given by:

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

The time-varying and skill-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 labor, which is given by $ES_{u,s} = ES_{1,2} = ES_{1,3} = \frac{1}{1-\rho}$,

[20] An alternative to the CES is the translog function. However, the translog has many more parameters to estimate, which would significantly reduce the degrees of freedom in an already small sample.

[21] See Manacorda, Sanchez-Paramo and Schady (2006).

while θ determines the ES between intermediate and higher education, which is given by $ES_{2,3} = \frac{1}{1-\theta}$.[22] If either ρ or θ is zero, the corresponding nesting is Cobb-Douglas. If $\rho > \theta$, the elasticity of substitution between higher and intermediate is lower than the one between either higher or intermediate and basic education, which means that there are complementarities in production between intermediate and higher education.

The labor input is measured in efficiency units: each input type is the product of the raw number of labor units of that type and the efficiency index defined in equation (2). 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:

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

where $h^j_{i,t}$ is the supply of education level j of individual i in year t expressed in efficiency units.

Differently from physical capital, labor is not internationally mobile and its remuneration is set domestically. Under the assumption of perfectly competitive markets and profit maximization by firms, the price for education level j in year t, $p_{j,t}$, is given by the marginal product of the jth aggregate human capital:

$$p_{1,t} = G_t(1-\delta_{s,t})H_{1,t}^{\rho-1} = \frac{\partial Y_t}{\partial H_{1,t}} \tag{12}$$

$$p_{2,t} = G_t(\delta_{s,t})[\alpha_{3,t}H_{3,t}^{\theta} + (1-\alpha_{3,t})H_{2,t}^{\theta}]^{\frac{\rho-\theta}{\theta}}(1-\alpha_{3,t})H_{2,t}^{\theta-1} = \frac{\partial Y_t}{\partial H_{2,t}} \tag{13}$$

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

where $G_t \equiv Y_t(1-\alpha)\frac{1}{[\delta_{s,t}H_{s,t}^{\rho} + (1-\delta_{s,t})H_{u,t}^{\rho}]}$.

By taking the ratios of the equations above, I can derive the expressions for the relative

[22] 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.

returns to schooling:

$$\frac{p_{2,t}}{p_{1,t}} = \frac{\delta_{s,t}}{(1-\delta_{s,t})}(1-\alpha_{3,t})\left(\frac{H_{1,t}}{H_{2,t}}\right)^{1-\rho}\left\{(1-\alpha_{3,t})+\alpha_{3,t}\left[\frac{H_{3,t}}{H_{2,t}}\right]^{\theta}\right\}^{\frac{\rho-\theta}{\theta}} \tag{15}$$

$$\frac{p_{3,t}}{p_{2,t}} = \frac{\alpha_{3,t}}{(1-\alpha_{3,t})}\left(\frac{H_{3,t}}{H_{2,t}}\right)^{\theta-1} \tag{16}$$

$$\frac{p_{3,t}}{p_{1,t}} = \frac{\delta_{s,t}}{(1-\delta_{s,t})}\alpha_{3,t}\left(\frac{H_{1,t}}{H_{3,t}}\right)^{1-\rho}\left\{\alpha_{3,t}+(1-\alpha_{3,t})\left[\frac{H_{2,t}}{H_{3,t}}\right]^{\theta}\right\}^{\frac{\rho-\theta}{\theta}} \tag{17}$$

where equations (15), (16) and (17) define, respectively, the relative returns to intermediate versus basic, higher versus intermediate and higher versus basic education.

The degree of complementarity between intermediate and higher education is an important determinant of the changes in relative returns. An increase in the amount of human capital at intermediate level has two different effects: 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 (15) and (16). For a given supply of basic and higher human capital, an increase in H_2 decreases the relative return to intermediate with respect to basic education and increases the relative return to higher with respect to intermediate education. The CE is given by the term in curly brackets in equation (15) and (17). 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 return to intermediate with respect to basic education and increases the relative return to higher with respect to basic education.

Activities of the government are not central to the analysis. The government neither collects taxes nor redistributes them.

3.3 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 skill prices,

$p_t = [p_{1,t,}p_{2,t}, p_{3,t}]$, aggregate labor 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 labor supply of education j, $j_{a,t}$, individual labor 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 labor 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.

A standard solution method based on backward recursion and value function iterations is used to solve the model and to compute the equilibrium steady state. The full solution method is described in Appendix B.

4 Estimation and calibration

This section discusses how I parametrize the model economy. I first estimate the wage equations and the production function. Then, given the estimated parameters, I calibrate the rest of the parameters.

I estimate the model using data from Mexico that together with changes in the supply of education was characterized by significant changes in the demand for it.[23] Mexico provides

[23] During the 1990s Mexico promoted a series of economic reforms that changed the structure of production

a very good example of the reform effort that characterized Latin America in the 1990s and resulted into an increased demand for skilled labor in production.[24]

4.1 Estimation

4.1.1 Wage equations

In order to estimate the parameters characterizing the wage equations and the structure of the error term as specified in equation (1) and (2), I would need 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.[25] Also, until 2004 there were no standardized measures of test scores.[26] The only available data set with information on wages and a panel dimension following individuals over the 1990s is the Mexican Employment Survey, the ENEU (*Encuesta Nacional de Empleo Urbano*). A description of the ENEU is presented in Appendix A.

The ENEU collects wage information on the Mexican urban population of workers at least twelve years old over five consecutive quarters, the four quarters of a given year and the first of the following year. I consider the four quarters of a given year and I specify the

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and made the economy more open to foreign investment. The reform effort culminated in 1994 when Mexico became a member of the Organization for Economic Cooperation and Development (OECD) and entered the North American Free Trade Agreement (NAFTA) with the US and Canada. In 1994 Mexico was also hit by a severe financial crisis, the "Peso crisis", which resulted into a massive devaluation of the national domestic currency. Verhoogen (2008) finds that it was the Peso crisis more than any economic reform that resulted into an increase in the use of skilled labor. Overall, disregarding the specific mechanism through which it happened, all contributions agree that in the 1990s Mexico underwent a structural change towards the use of skilled labor in production.

[24] Goldberg and Pavcnik (2004) and Winters, McCulloch and McKay (2004) provide two exhaustive surveys of the literature.

[25] 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.

[26] 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.

following log wage equation for individual i with education level j in quarter qr:

$$\ln w^i_{j,qr} = \ln w_{j,qr} + g_j(age^i_{qr}) + u^i_{j,qr} \qquad j = 1, 2, 3 \tag{18}$$

$$u^i_{j,qr} = \eta^i + z^i_{j,qr} \tag{19}$$

$$z_{j,qr} \sim N(0, \sigma^2_{z_{j,qr}}) \tag{20}$$

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 and reflect average productivity of workers with the j level of education, $g_j(.)$ is an education-specific quadratic polynomial in age that proxies for experience in the labor market, η^i is a permanent individual-specific effect and $z^i_{j,qr}$ is an i.i.d. shock received by the individual i with education level j in quarter qr.

I construct panels of individuals by matching workers by the position in an identified household, the number of years of education and age. I consider all wage workers between the age of 15 (minimum legal working age) and 60 (average retirement age) and I follow them over the four successive quarters in a given year. For each year of the sample between 1987 and 2002 I run the following fixed effects regression:

$$(\ln w^i_{j,qr} - \ln \overline{w}^i_j) = (\ln w_{j,qr} - \ln \overline{w}_j) + g_j(age^i_{qr}) - g_j\overline{(age^i)} + (u^i_{j,qr} - \overline{u}^i_j) \tag{21}$$

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 we require the unconditional distribution of ability as reflected by the fixed effect, η^i. I use the estimate:

$$\widehat{\eta}_i = \frac{\sum_{t=1}^{T(i)} \ln w^i_{qr} - \widehat{\ln w_{qr}} - \widehat{g(age^i_{qr})}}{T(i)} \tag{22}$$

where $T(i)$ is the total number of observations available on individual i. The estimated fixed-effects give an estimate of the distribution of η for the working population.[27] The results of the estimation are reported in Appendix C.[28]

4.1.2 Production function

The identification of the parameters of the production function requires knowledge of the aggregate human capitals, which are the sum of the efficiency weighted labor supply of workers with a given level of education. The efficiency index defined in equation (2) is intrinsically unobserved. The method used to approximate the aggregate human capital series combines different information sources as in Heckman, Lochner and Taber (1998).

Let us define the wage bill $WB_{j,t}$ as the total earnings' payments received by the individuals of a given education group in a given year. Then:

$$WB_{j,t} = \widehat{p}_{j,t} * \widehat{H}_{j,t} \qquad j = 1, 2, 3 \tag{23}$$

where $\widehat{p}_{j,t}$ is the estimated market price of workers with education level j in year t and $\widehat{H}_{j,t}$ denotes the estimated value of human capital j at time t.

Therefore:

$$\widehat{H}_{j,t} = \frac{WB_{j,t}}{\widehat{p}_{j,t}} \qquad j = 1, 2, 3 \tag{24}$$

Normalizing to one the value of each of the $\widehat{p}_j$ in 1987, it is possible to identify the series of the utilized human capital stocks normalized to 1987.

In order to compute the wage bills we need a data set that is representative of the entire Mexican population. The ENEU collects information on urban areas only so it can not be used to this purpose. I use instead the ENIGH, that is nationally-representative and reports individual earnings together with detailed information on assets and consumption. For each year and education group I compute the wage bill by summing over the individual earnings of all primary wage earners between the age of 15 and 60. I linearly interpolate the available

[27] The distribution of ability is taken to be time-invariant. I therefore abstract from any heterogeneity in ability endowments between successive cohorts active in the labour market in different years.

[28] The short length of the panel biases the estimates of the fixed effects. Section 6 will discuss the robustness of the quantative importance of changes in the initial distribution of ability to produce the convexification.

data for missing years. The total number of workers and the wage bills by level of education are presented in Appendix C.

In order to obtain an estimate of the $p_{j,t}$ I run the fixed effect regression described in equation (21) for each year between 1987 and 2002 and I compute the predicted mean log hourly real wage for each education level net of the fixed effects, which gives an estimate of the log skill prices by level of education in each year of the sample. Given the wage bills and the (log) skill prices, I divide the wage bills by the exponentiated value of the skill prices 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.[29] The estimated skill prices and human capital series normalized to 1987 are presented in Appendix C.

Having a measure of the aggregate human capital series and of the education prices and having assumed that the aggregate inputs are paid their marginal product, the first order conditions of the firms' maximization problem (equation (12) to (14)) provide the structure to identify the parameters of the production function. Following a wide literature on the estimation of the production functions, which started with the seminal contribution of Katz and Murphy (1992), I use the changes in the relative supply of education to identify the changes in relative demand.

Log linearizing equation (16), I obtain:

$$(\log p_{3,t} - \log p_{2,t}) = [\log \alpha_{3,t} - \log(1-\alpha_{3,t})] + (\theta - 1)(\log H_{3,t} - \log H_{2,t}) \tag{25}$$

where $\log \alpha_{j,t}$ denotes the time series of the relative demand shifts for skill level j measured in log quantity units.

By rewriting the above expression in terms of wage bills we obtain:

$$(\log WB_{3,t} - \log WB_{2,t}) = [\log \alpha_{3,t} - \log(1-\alpha_{3,t})] + \theta(\log \widehat{H}_{3,t} - \log \widehat{H}_{2,t}) \tag{26}$$

[29] 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, to derive an estimate of the time series of education prices they use the average wages by year and level of education for the workers aged 45 or more in their sample. By following the same procedure, we can estimate the skill price ratios by 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.

where $\widehat{H}_{3,t}$ and $\widehat{H}_{2,t}$ denote the estimates of the human capital of workers with, respectively, higher and intermediate education at time t.

Equation (26) can be used to obtain a direct estimate of the elasticity of substitution between higher and intermediate education. 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:

$$\log \alpha_{j,t} = \phi_{0,j} + \phi_{1,j} * t + e_{j,t} \tag{27}$$

where $\phi_{0,j}$ is a skill-specific constant, t denotes a linear time trend and $e_{j,t}$ is a normally distributed i.i.d. shock at time t for skill level j.[30]

Combining equation (26) and (27), 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 log wage bills on the ratio of the human capital aggregates, a linear trend and a constant. In order to correct for the endogeneity of the human capitals, I apply an IV estimator using as instrument the first lag of the difference of the logs of the human capital factors.

Then, I use equation (10) above to construct a measure of skilled human capital 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 (26) and (27) 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.

The results of the estimation are reported in Table 1. The table presents the estimates obtained for higher versus intermediate education and for skilled versus unskilled. The last row of the table reports the value of the implied elasticity of substitution, which is computed as one over one minus the coefficient of the difference of log H in the corresponding column.

[30] Given the spike in the wage bills in 1994, I tried alternative specifications that allow the trend to vary for the pre and post 1994 period. However, the interaction term was never significant.

The magnitude of the ES reported in Table 1 is consistent with the results of the previous empirical studies that have estimated a production function with three types of human capital using data from Latin America.[31]

Parameter	*Higher versus Intermediate*	*Skilled versus Unskilled*
Difference log H	0.7726	0.8601
	(0.0636)	(0.1362)
Time trend	0.0262	0.0135
	(0.0048)	(0.0065)
Constant	−51.9469	−26.0616
	(9.5317)	(13.0620)
Implied ES	4.4	7.1

Table 1: Estimation of the Production Function, Standard Errors in Parenthesis. Unskilled are workers with basic education. Skilled is the sum of workers with intermediate and higher education.

The implied ES between workers with higher and intermediate education is lower than the one between workers with either higher or intermediate and basic education. This is consistent with the presence of complementarities in production between workers with intermediate and higher education.

A joint estimation of the system of equations to test for the equality of the coefficients of the log relative supplies confirms that ρ and θ are statistically significantly different. The test gives a value of chi-squared of 7.1 with a P-value of 0.0077. I also test for the assumption of equality between $ES_{3,1}$ and $ES_{2,1}$, which is a restriction imposed by the symmetry of the CES operator. The test gives a value of chi-squared of 0.35 with a P-value of 0.5525. Therefore, the test can not reject the null hypothesis of equal coefficients.

The coefficient of the time trend gives an estimate of the yearly relative demand of higher with respect to intermediate-educated, $(\phi_{1,3} - \phi_{1,2})$, and of skilled with respect to unskilled labor, $(\phi_{1,s} - \phi_{1,u})$. I call $(\phi_{1,s} - \phi_{1,u})$ the "skill-bias" parameter. As can be seen from Table 1, I estimate an increase in the relative demand for skilled labour of around 1.35% a year.

[31] See Manacorda, Sanchez-Paramo and Schady (2006) that use a cross section of Latin American countries that includes Argentina, Brazil, Chile, Colombia and Mexico. The estimated ES for Latin America are significantly bigger than the typical values for the ES found in empirical studies that use US data (Katz and Murphy, 1992).

4.2 Calibration

Given the estimation of the wage equations and the production function, I calibrate the rest of the parameters. The complete list of the parameters together with their value, a description and the target used in the calibration is reported in Figure 8 in Appendix C.

4.2.1 Initial distribution of wealth and education

I set the initial distribution of education using the 1987 wave of the ENEU. I divide the workers into two categories: the adult population that is made up by all heads of households aged between 25 and 60 with basic, intermediate and higher education and the population of young living with their parents aged between 15 and 24 with completed basic and intermediate education. I use the mean proportions by education in the adult population to set the initial education distribution of the parents and the mean proportions of the young with basic and intermediate education for the education distribution of the children in the third and fourth periods. In the pre-school period all children have by definition zero education. In the second period they all complete compulsory basic education.

The ENEU does not record information on wealth. I use instead the Mexican Expenditure Survey, the ENIGH (*Encuesta Nacional de Ingresos y Gastos de los Hogares*), which is available in 1984, 1987 and every two years since then and contains detailed information on individuals' consumption and assets. I set the initial wealth distribution to a lognormal with mean and standard deviation computed from the distribution of financial assets of the workers aged between 25 and 60 in 1992.[32]

4.2.2 Preferences and costs of schooling

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). The value is taken from Arrau and van Wijnbergen (1991) that estimate for Mexico a value for the EIS between a lower bound of 0.8 and an upper bound of 1.4. The limit on net indebtedness, B, is set to zero, which

[32] 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, I parametrize the wealth distribution using the first and second moments of the 1992 instead of the 1987 wave. The results of the simulations are robust to matching more moments of the wealth distribution and to relaxing the assumption of it being lognormal.

corresponds to the maximum level of credit constraints. Consumption is adjusted to account for the presence of the child. I use an equivalence scale equal to 0.7 for a child reflecting 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.

I set the values of the fixed costs of schooling, F_j, for each jth education level so that the model matches the education distribution of the workers aged between 25 and 60 in the ENEU in 1987. I find $F_1 = 0.035$, $F_2 = 0.26$ and $F_3 = 0.64$, which implies that the costs at intermediate level are around seven times the ones at primary and the costs at higher education are around eighteen times the ones at primary.[33]

4.2.3 Interest rate and capital share

The value of the real interest rate, r, is set to a US benchmark value. I choose a value of five per cent, which is the average real interest rate on the US 6-months Treasury Bills published by the Federal Reserve Board for the period between the year 1990 and 2000. Given an average working life of the adult Mexican population of approximately thirty years, the model period is set to seven 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 equal to 0.35, which is the average value between the lower and the upper bound that has been estimated for LACs.[34]

[33] Education in Mexico is free in public schools while private education is expensive at all levels. The ENEU does not record information on the type of school attended, so it is not possible to distinguish between public and private schools. The F_j in the model measure the average total direct costs of education, which includes fees, costs of school material and maintanance. An empirical counterpart of these costs is provided by the first wave of the MxFLS, which collects high quality data on a rich set of variables for a cross section of Mexican households in 2002. The Survey contains a detailed set of questions on education costs and distinguishes between tuition fees, the costs of exams, books, school material, uniforms and the maintenance costs for public and private schools. Summing over the different categories and computing the mean for public and private education, the costs of intermediate education are around eight times the ones at primary while the ones at higher education are around nineteen times the ones at primary.

[34] See 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 LACs.

5 Simulations

In this section I simulate the model economy for a quantitative assessment of the role of the two key components of the model to produce the convexification: the complementarities in the production function and the joint education-savings decisions under credit constraints.

I define the baseline economy as the one characterized by the values of the parameters estimated and calibrated for 1987. The baseline model matches the education shares observed in Mexico in 1987 and it is characterized by a linear relationship between the prices and the level of education. Then, I assess the impact of an exogenous increase in the demand for skilled labor, which I call "skill-biased technological change" (SBTC hereafter), on the education prices in different scenarios.

I define two series of counterfactuals. First, I compute the impact of a SBTC by keeping all structural parameters fixed at baseline values. The supply of education will react to the increase in the demand of skilled labor and this will have an impact on the education prices. The size and the direction of the equilibrium effects depend on the degree of substitutability between the aggregate human capital. The estimation results in Table 1 show that the elasticity of substitution between workers with intermediate and higher education is lower than between any of these two groups and workers with basic education. I compare the education prices at steady state that the model produces with the complementarities between intermediate and higher education and without them, that is by assuming that the production function is isoelastic with $ES_{u,s} = ES_{1,2} = ES_{1,3} = ES_{2,3} = \frac{1}{1-\rho}$.

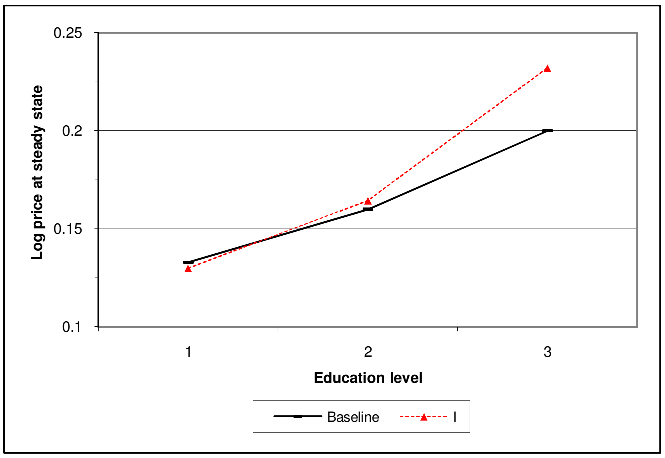
Second, I assess the impact of a SBTC combined with a relaxation of the credit constraints.

5.1 Skill-biased technological change and no borrowing

A SBTC is modelled as a permanent increase of δ_s, which measures the contribution of skilled labor to the production of the aggregate output. An increase in its value is to be interpreted as an increase in the productivity or in the demand for skilled labor. The size of the increase is given by the "skill-bias" parameter obtained from the estimation of the production function. As shown in Table 2, I estimate a value of the "skill-bias" of around

1.35 per cent a year.[35] I use the baseline value of δ_s in 1987 to define the no skill-biased technological change scenario.[36] Then, a SBTC is modelled as an increase of δ_s by 1.35 per cent a year for five consecutive years and constant at the increased value from the sixth year onwards.[37]

Figure 2: Steady State Skill Prices With Skill-Biased Technological Change and No Borrowing.



I define a first counterfactual, Scenario I, which is characterized by a SBTC and all other parameters fixed at baseline values. Figure 2 presents the equilibrium (log) skill prices in the baseline model and in Scenario I. At baseline the model matches the education shares in 1987 and produces a linear relationship between the log prices and the level of education. Once the share of skilled labor increases, Scenario I results into a steep increase in both the premium to higher and to intermediate education. As clear from equations (12) to (14) and the fact that $\delta_u = (1-\delta_s)$, an increase in δ_s decreases the equilibrium price at basic education and increases the prices at both intermediate and at higher education. The increased prices at intermediate and higher education give incentives to invest after compulsory schooling. As

[35] This is consistent with the previous results found for Latin American countries (Manacorda, Sanchez-Paramo and Schady, 2006).

[36] Using the wage bill equation for skilled and unskilled, the equivalent of equation (27) for $\delta_{s,t}$ 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 $\alpha_{3,t}$ as explained in Section 4.1.2. For the year 1987, I obtain a baseline estimate of 0.55 for α_3 and of 0.692 for δ_s.

[37] Simulating the model with increases of δ_s of longer and shorter duration produces qualitatively similar results.

expected and consistently with the fixed costs of education being lower at intermediate than at higher education ($F_2 < F_3$), the supply of workers with intermediate education increases more than the one of workers with higher education, so the price at intermediate decreases more than at the higher level.

The size and the direction of the equilibrium effects depend on the degree of subtitutability between aggregate labor inputs. The results of the estimation of the production function in Section 4.1.2 show that there are complementarities in production between intermediate and higher education. If higher and intermediate education are more complementary than higher and basic (or intermediate and basic), in addition to the standard supply effect, an increase in H_2 further decreases the relative return to intermediate with respect to basic education and increases the relative return to higher with respect to basic education.

Figure 3: Steady State Skill Prices With Skill-Biased Technological Change and Production Complementarities Versus Isoelastic Production Function.

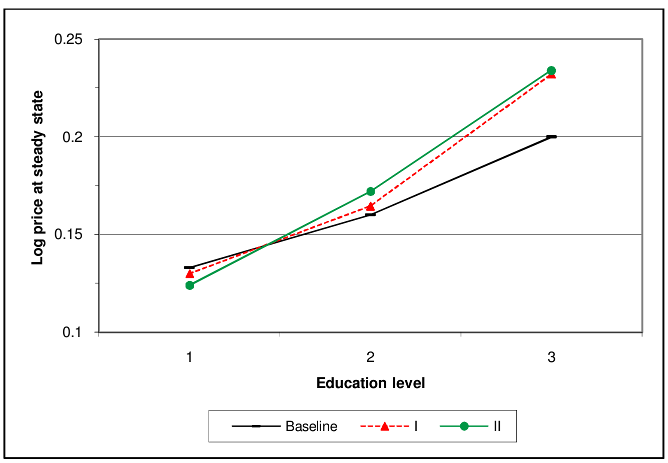


Figure 3 quantifies the importance of the complementarities between intermediate and higher education. I define a second counterfactual, Scenario II, which assumes that the production function is isoelastic, that is $\rho = \theta$ and therefore $ES_{u,s} = ES_{1,2} = ES_{1,3} = ES_{2,3} = \frac{1}{1-\rho}$.

As it is clear from Figure 3, in the absence of complementarities between intermediate and higher education, the equilibrium price schedule is back to being a linear function of the level of education.

Scenario I does match the first feature of the convexification, that is the increase in the relative returns to higher education and the decline in the relative returns to intermediate education. However, it does not match the second feature of the convex shift, that is the drop of the price at intermediate below the value at baseline. The extent of the decrease of the price at intermediate depends on the size of the supply increase at this level. The main constraint that prevents the supply to increase is the extent of the credit constraints. All the simulations up to now have been obtained by keeping all structural parameters fixed at baseline values. At baseline $B = 0$, that is borrowing is not allowed. Starting from Scenario I, I now assess the impact of allowing for borrowing.

5.2 Skill-biased technological change and relaxation of the credit constraints

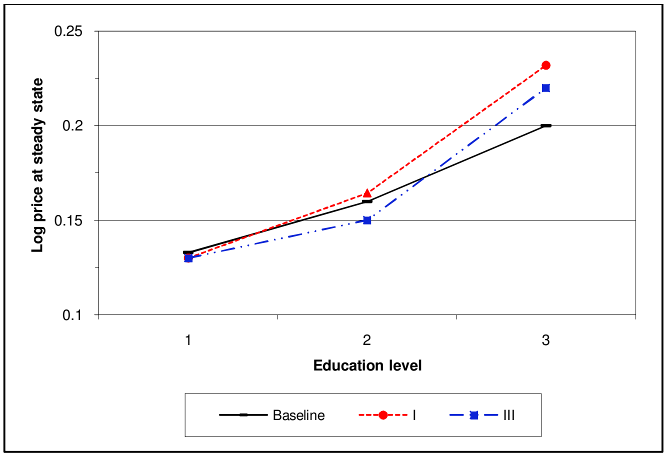
I define a third counterfactual, Scenario III, that is given by Scenario I with a relaxation of the credit constraints to the upper bound of the values that B can take.[38] Figure 4 reports the price schedule at steady state in the baseline and in Scenario I and III.

With respect to Scenario I, the possibility of borrowing allows more people to complete intermediate and higher education, so investment in human capital at both levels increases and therefore the equilibrium prices at intermediate and higher education decrease. However, the supply increase at intermediate level does not translate into a proportional increase at higher education, so the price at intermediate decreases more than at the higher level.

As expected, there is a positive relationship between the borrowing limit and the size of the supply increase at intermediate: the more it is possible to borrow, the higher is the investment in education after compulsory schooling. Unreported results show that there is a borrowing threshold of around forty per cent of individuals' lifetime earnings below which

[38] As I discussed in section 3.1, 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.

Figure 4: Steady State Skill Prices With Skill-Biased Technological Change and Relaxation of the Credit Constraints.



the size of the supply increase at intermediate is not enough to produce a sizeable decrease in the equilibrium price below the value at baseline.

Scenario III presents both of the two features that characterize the convexification in Mexico: with respect to the baseline model, the relative return to higher versus intermediate education increases, the relative return to intermediate versus basic education decreases and the price at intermediate lies below the value at baseline.[39]

6 Model's assessment

For a quantitative assessment of the model's performance we can compare the growth of the skill prices and the relative returns computed from the simulations and from the data. The second column of Table 2 and 3 presents, respectively, the growth of the level and of the relative log education prices between 1987 and 2002 estimated from equation (21) with the ENEU data; columns three to six present, respectively, the growth of the level and of the relative log education prices computed at steady state in each of the three simulated

[39] An additional constraint to an increase in the supply of education is given by the extent of earnings' risk. Negative shocks can change the fortune of dynasties that are born rich and prevent some families to finance investments into higher education. A proxy for earnings' risk is given by the value of the estimated variances of the earnings as reported in Table 6 in Appendix C. Simulation results show that in the absence of a relaxation of the credit constraints changes in earnings' risk on their own would not be able to produce the convexification. All results are available from the author upon request.

scenarios with respect to the baseline model. The change in both the level of the skill prices and in the relative returns in Scenario III is close in magnitude to the ones estimated from the ENEU.

Log education prices	ENEU (1987-2002)	Scenario I	Scenario II	Scenario III
Basic	−3%	−2%	−7%	−2%
Intermediate	−5%	3%	7%	−6%
Higher	6%	16%	17%	10%

Table 2: Growth of the Log Education Prices in the ENEU Data Between 1987 and 2002 and in the Three Simulations With Respect to the Baseline Model

Log relative education prices	ENEU (1987-2002)	Scenario I	Scenario II	Scenario III
Higher versus Intermediate	72%	69%	55%	75%
Higher versus Basic	25%	52%	64%	34%
Intermediate versus Basic	−15%	28%	78%	−26%

Table 3: Growth of the Relative Log Education Prices in the ENEU Data Between 1987 and 2002 and in the Three Simulations With Respect to the Baseline Model

Overall, the simulations show two important results: first, consistently with the preliminary evidence presented in Section 2.1, the convexification was not driven by changes in the composition of ability but rather by changes in the prices of skills. Second, the changes in the prices resulted from the supply response to an increased demand for skilled labour in the presence of production complementarities between intermediate and higher education and a relaxation of the credit constraints on the supply of human capital.

I now assess the robustness of both these two results starting with the changes in the ability composition. The changes in the supply of education that resulted into the convexified profile did modify the ability composition by level of education. Table 4 presents the mean and the standard deviation of the ability distribution by education at Baseline and in Scenario III. As expected, the supply increase of intermediate-educated resulted into a sharp decline of the mean ability level for this group and into an increase in the mean ability at basic education. Due to the entrance of low-ability individuals together with high-ability ones the mean ability level did also decline at higher education. However, the reduction in mean ability at intermediate was of a much bigger magnitude than the one at higher education.

Therefore, with respect to the Baseline, in Scenario III the ability gap between higher and intermediate education increased sharply.

Ability by Education	Baseline		Scenario III	
	mean	sd	mean	sd
Basic	−0.226	0.396	0.311	0.276
Intermediate	0.396	0.314	−0.191	0.436
Higher	0.615	0.283	0.358	0.536

Table 4: Mean and Standard Deviation of Ability by Education at Baseline and in Scenario III

The quantitative importance of the changes in ability composition is sensitive to the specific ability distribution estimated from the data. There could be 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 profile as a result of compositional changes. We can simulate the model when we arbitrarily change the moments of the 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 (2009) is the only paper that provides an estimate of the changes in the ability composition by level of education in a Latin American country in the 1990s. Binelli et al. (2009) distinguish between four levels of schooling and estimate the changes in ability composition by education and birth cohort during the Brazilian educational expansion in the 1990s.

The estimates of Binelli et al. (2009) provide a precise benchmark of the magnitude of the shifts in ability composition by level of education in Latin America in the decade of the 1990s and can therefore be used for a robustness test of the quantitative importance of the changes in the composition of ability to produce the convexification.

I simulate the model at constant skill prices and I compute the changes in mean ability that would be necessary to produce the convexified profile. Unreported results show that the mean ability level at intermediate education would have had to decrease five times more than the relative decrease in ability at this level that Binelli et al. (2008) estimate for Brazil. So, it was not changes in ability composition per se to produce the convexification but rather a combination of composotional changes and changes in the prices of education with the latter being of fundamental importance.

I now turn to the second main result of the simulations, that is that the changes in the prices of education resulted from the interaction between the demand and the supply of education. As it is clear from equations (12) to (14), the same changes in the prices of education that characterize the convexified profile in Scenario III could be obtained by changing the share of skilled and unskilled labor so that the demand for education changes while the supply of education does not. Unreported results show that by keeping the supply of education constant at the values observed in 1987, the increase in the demand for skilled labour that was necessary to produce the convexified profile would be more than three times bigger than the 1.35 per cent a year estimated from the data. So, the supply response to the increased demand for skilled labor was a crucial determinant of the convex shift.

As for the two mechanisms via which the changes in the supply resulted into the changes in the prices of education, both the production complementarities and the relaxation of the credit constraints do find empirical support. The production complementaries between medium and highly educated workers are consistent with an economy with two main sectors, a first one that employs low-skilled labor and a second one where production is carried out by using semi and high-skilled labor. This structure of production is a good description of the Mexican economy that is characterized by two main sectors: a formal sector of semi and high-skilled workers and an informal sector of low-skilled workers.[40]

As for the relaxation of the credit constraints, the decade of the 1990s in Mexico was characterized by 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 the amount in 1994.[41]

Finally, the model abstracts from a number of facts that could have potentially been

[40] By defining a worker as "formal" if paying social security contributions in either the private or the public sector, evidence from the Mexican Employment Survey shows that in the 1990s almost eighty per cent of formal sector workers have at least completed high school education.

[41] The most recent available data show that the steep increase in consumer credit 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.

important to explain the convexification. First, I do not model changes in wage setting institutions such as the minimum wage or the level of unionization. As discussed by Maloney and Nunez (2003), in Latin America the impact of the changes in labor market institutions was mainly concentrated at the bottom end of the distribution. It could be that the extent of the fall of the wages at basic education was limited by the presence of binding minimum wages. However, with the exception of Colombia, the empirical evidence for Latin America suggests that in the 1990s minimum wages were not binding.[42] The evidence for Mexico shows that the drop in the mean wages at basic education was of a much smaller size than the one of the minimum wages: between 1987 and 2002 minimum wages declined in real terms by around 47 per cent while wages at basic education decreased by less than four percentage points.

Second, I do not model social welfare programs and education subsidies that give incentives to invest in education. In Mexico the main education programs (the most famous one being "Progresa" later called "Opportunidades") started at the end of the 1990s, so they can not the main determinant of the convex wage shift that arise during the 1990s.

Third, I do not model migration. In the 1990s there were vast migration flows from Mexico to the US. However, the Mexixo-US migration was mainly an outflow of low-skilled workers with two thirds of the adult Mexican immigrants having not completed intermediate education.[43] The low-skilled migration on its own could not explain the double change in the relative wages even if it could have contributed to reduce the fall in the wage at basic education and therefore to produce the decline in the relative returns to intermediate education.[44] It could be interesting to disentangle the downward pressure on wages due to the demand decrease for low-skilled workers and the upper pressure due to the migration of this type of workers to the US. This is left for future research.

[42] See Maloney and Nunez (2003) and Bosch and Manacorda (2008).

[43] Report of the US Center for Immigration Studies, 2001 that is available at www.cis.org

[44] Also, migration does not seem to be a root cause of the convexification since vast migration outflows were observed in the 1990s from Mexico but not from the other countries that were also characterized by a change of the wage profile from linear to convex.

7 Conclusion

This paper studies a central feature that characterizes the changes in wage inequality in the decade of the 1990s in many countries: the relationship between log wages and the level of education convexified. The higher-intermediate wage differential increased and the intermediate-basic wage differential declined.

These wage changes have important implications for the process of human capital accumulation. The non-linearity of the wage function changes the opportunity costs of investing in education which becomes profitable only if college 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 up to the end of college. In addition, a convex wage profile implies that inequality is growing faster at the top rather than at the bottom of the wage distribution with increasing benefits for the very rich, which raises serious equity and distributional concerns.

I show that the changes in both the relative wages and in the level of wages can be explained by a two-way interaction between the demand and the supply of education. The production complementarities between intermediate and higher education are responsible for the double change in the wage differentials while a relaxation of the credit constraints explains the drop of the wage at intermediate and therefore the extent of the convexification. This argument is supported by an empirical equilibrium model of savings and educational choices estimated with micro-data for Mexico.

The mechanism proposed in this paper cannot pretend to be a complete explanation of the changes in wage inequality. The intention is not to provide a model that gives a universal answer, but rather a framework that shows how accounting for the structure of production and the interaction between the demand and the supply of education is of key importance to explain the evolution of wage inequality.

Then I believe that the exact mechanisms through which the demand and the supply interact and result into the observed wage changes are country-specific. Two interesting case studies would be the US and the booming economies of East Asia. In the US changes in labor market institutions rather than credit constraints[45] and complementarities between

[45] 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.

skilled labour and physical capital rather than between intermediate and higher educated[46] could be two important model's additions to explain the determinants of the convexification. In the fast growing economies of East Asia an important factor to include in the model could be international trade.[47]

Finally, this paper provides a framework to address an interesting and related question concerning the timing of the convexification. Following the recent empirical literature on dynamic equilibrium models[48], the model could be used to study the economies in transition from the beginning to the end of the 1990s. The aim would be to explain the dynamics of changes in the prices and in the distribution of education that resulted into the convex wage shift. A welfare analysis of who has been winning and losing during the transition and by how much would complete the quantitative exercise. This is left for future research.

[46] Using US data and a model of endogenous technological adoption, Beaudry and Green (2005) argue that capital-skill complementarities could be the main factor explaining the changes in the level of low-skilled wages and in the high-low skilled wage differential. Beaudry and Green (2003) show that capital-skill complementarities could be the main determinant of the differences between the changes in wage inequality observed in the US and in Germany from the beginning of the 1980s to the mid 1990s.

[47] Wood (2002) proposes a unified theory based on falling co-operation costs between rich and poor countries that induce a decrease in wage inequality in the lower part of the distribution and an increase in the upper part of the distribution in the rich countries. Using US data, Anderson, Tang and Wood (2006) provide supporting empirical evidence to the qualitative predictions of the model.

[48] See, for example, Lee and Wolpin (2006) and Johnson and Keane (2007).

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NOT FOR PUBLICATION
Appendix A - ENEU

The ENEU (*Encuesta Nacional de Empleo Urbano*) is the Mexican national employment survey collected yearly by the Mexican national statistical office, INEGI. The ENEU has a structure similar to the US Consumer Expenditure Survey (CEX). It is a quarterly household survey that collects individual-level data and it has a rotating panel structure: households are interviewed for five consecutive quarters and in each quarter twenty per cent of the households are replaced by new households that are interviewed for the first time. The survey started in 1981 with progressive increase of the geographic coverage. The sample is selected to be geographically and socio economically representative of the Mexican urban population: by the end of the 1990s it covered approximately sixty two per cent of the national urban population and ninety two per cent of the cities with population greater than one hundred thousand people. By the end of the 1990s, approximately seventy four per cent of the Mexican population lived in urban areas. Recent rounds of the ENEU have national coverage, but since the earlier ones survey urban areas only, I restrict the sample to urban areas in all years.

The main questionnaire is divided in three parts. The first part collects socio demographic information on all household members. The second part contains detailed employment information on individuals at least twelve years old. The third part reports information on the characteristics of the house of residence with additional questions on the characteristics of the building, number and type of rooms and ownership status from the 1994 wave onwards. The employment information is very detailed with several questions on individuals' 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. Earnings are reported net of all labor taxes and social contributions paid in either public or private funds. I compute hourly wages as the ratio between monthly earnings and hours worked in the main occupation last month. I deflate the data using the Mexican national CPI June 2002.

Appendix B - Solution method

This Appendix describes the method used to compute the equilibrium steady state. The model is solved recursively by backwards induction from the last to the first period of adult life.

Step 1. Set an initial guess for the vector of skill prices $[p_1, p_2, p_3]$ and assume that future prices equal current prices.

Step 2. Solve the optimization problem in the last period of work life before retirement $(a = \overline{a})$.

Define with $V_{\overline{a}}^{Sch}(j^P, j_{\overline{a}}^C, A_{\overline{a}}, p(\overline{a}), \eta, z_{\overline{a}})$ and with $V_{\overline{a}}^{Work}(j^P, j_{\overline{a}}^C, A_{\overline{a}}, p(\overline{a}), \eta, z_{\overline{a}})$, respectively, the conditional value function of sending the child to school and to work and denote with $W_{\underline{a}}^{Sch}(j_{\underline{a}}^P, A_{\underline{a}}, p(\underline{a}), \eta, z_{\underline{a}})$ and $W_{\underline{a}}^{Work}(j_{\underline{a}}^P, A_{\underline{a}}, p(\underline{a}), \eta, z_{\underline{a}})$ the initial guess for child lifetime utility as an adult conditional on having sent the child, respectively, to school and to work in the last period of coresidence. $\underline{a}$ denotes the age of the parent in the first period of adult life.

Given $W_{\underline{a}}^{Sch}(.)$ and $W_{\underline{a}}^{Work}(.)$, $V_{\overline{a}}^{Sch}(.)$ and $V_{\overline{a}}^{Work}(.)$ take the following expressions:

$$\begin{aligned} V_{\overline{a}}^{Sch}(j^P, j_{\overline{a}}^C, A_{\overline{a}}, p(\overline{a}), \eta, z_{\overline{a}}) &= \max_{c_{\overline{a}}} \left\{ U(c_{\overline{a}}) + \lambda\beta E_{z_{\underline{a}}} W_{\underline{a}}^{Sch}(j_{\underline{a}}^P, A_{\underline{a}}, p(\underline{a}), \eta, z_{\underline{a}}) \right\} \\ s.t. \quad c_{\overline{a}} &= A_{\overline{a}}(1+r) + w_{jP,\overline{a}} - F_{jC} - A_{\overline{a}+1} \\ j_{\underline{a}}^C &= (j_{\overline{a}}^C + 1) = j_{\underline{a}}^P \end{aligned} \tag{28}$$

$$\begin{aligned} V_{\overline{a}}^{Work}(j^P, j_{\overline{a}}^C, A_{\overline{a}}, p(\overline{a}), \eta, z_{\overline{a}}) &= \max_{c_{\overline{a}}} \left\{ U(c_{\overline{a}}) + \lambda\beta E_{z_{\underline{a}}} W_{\underline{a}}^{Work}(j_{\underline{a}}^P, A_{\underline{a}}, p(\underline{a}), \eta, z_{\underline{a}}) \right\} \\ s.t. \quad c_{\overline{a}} &= A_{\overline{a}}(1+r) + w_{jP,\overline{a}} + w_{jC,\overline{a}} - A_{\overline{a}+1} \\ j_{\underline{a}}^C &= j_{\overline{a}}^C = j_{\underline{a}}^P \end{aligned} \tag{29}$$

where r is the fixed real interest rate on financial assets, F_{jC} denotes the fixed costs of schooling for child education level j^C and $w_{jP,\overline{a}}$ and $w_{jC,\overline{a}}$ are, respectively, parental and child wage at age $\overline{a}$ given parental (child) education level $j^P(j^C)$. λ denotes the degree of parental altruism and expectations are taken over next period shock to earnings, z. Equations (28) and (29) describe the evolution of child education that increases by one unit if the child is sent to school. The level of child education at the end of the last period of coresidence defines the (fixed) education level throughout adulthood ($j^C_{\underline{a}} = j^P_{\underline{a}} = j^P$). For simplicity I do not report the credit constraints (equation (6)) and the terminal condition (equation (7)).

Step 3. Solve the conditional maximization problems in the third, second and first period of adult life.

In the third period child education is a choice variable. The conditional maximization problems read:

$$V_a^{Sch}(j^P, j_a^C, A_a, p(a), \eta, z_a) = \max_{c_a} \left\{ U(c_a) + \beta V_{a+1}(j^P, j_a^C + 1, A_{a+1}, p(a+1), \eta, z_{a+1}) \right\}$$
$$s.t. \quad c_a = A_a(1+r) + w_{jP,a} - F_{jC} - A_{a+1}$$
$$j_{a+1}^C = (j_a^C + 1)$$

$$\begin{aligned} V_a^{Work}(j^P, j_a^C, A_a, p(a), \eta, z_a) &= \max_{c_a} \left\{ U(c_a) + \beta V_{a+1}(j^P, j_a^C, A_{a+1}, p(a+1), \eta, z_{a+1}) \right\} \\ s.t. \quad c_a &= A_a(1+r) + w_{jP,a} + w_{jC,a} - A_{a+1} \\ j_{a+1}^C &= j_a^C \end{aligned}$$

where F_{jC} is the fixed cost of child schooling level j^C and $V_{a+1}(j_a^C+1, .)$ and $V_{a+1}(j_a^C, .)$ define, respectively, the expected value over the maximum between the conditional value functions of the schooling and work alternative in the next period given the decision of sending the child, respectively, to school or to work in the current period.

They take the following expressions:

$$\begin{aligned} & V_{a+1}(j^P, j_a^C + 1, A_{a+1}, p(a+1), \eta, z_{a+1}) \\ \equiv \; & E_{z_{a+1}} \max[V_{a+1}^{Sch}(j^P, j_a^C + 1, A_{a+1}, p(a+1), \eta, z_{a+1}), V_{a+1}^{Work}(j^P, j_a^C + 1, A_{a+1}, p(a+1), \eta, z_{a+1})] \end{aligned}$$

$$
\begin{aligned}
& V_{a+1}(j^P, j_a^C, A_{a+1}, p(a+1), \eta, z_{a+1}) \\
\equiv \quad & E_{z_{a+1}} \max[V_{a+1}^{Sch}(j^P, j_a^C, A_{a+1}, p(a+1), \eta, z_{a+1}), V_{a+1}^{Work}(j^P, j_a^C, A_{a+1}, p(a+1), \eta, z_{a+1})]
\end{aligned}
$$

In the second period the child is sent to compulsory basic education. The maximization problem is given by:

$$
\begin{aligned}
V_a(j^P, A_a, p(a), \eta, z_a) &= \max_{c_a} \left\{U(c_a) + \beta V_{a+1}(j^P, 1, A_{a+1}, p(a+1), \eta, z_{a+1})\right\} \\
s.t. \quad c_a &= A_a(1+r) + w_{jP,a} - F_1 - A_{a+1}
\end{aligned}
$$

where F_1 denotes the fixed costs of basic education and $V_{a+1}(1, .)$ defines the expected value over the maximum between the conditional value functions of the schooling and work alternative in the next period given that the child has completed compulsory basic education in the current period:

$$
\begin{aligned}
& V_{a+1}(j^P, 1, A_{a+1}, p(a+1), \eta, z_{a+1}) \\
\equiv \quad & E_{z_{a+1}} \max[V_{a+1}^{Sch}(j^P, j_a^C = 1, A_{a+1}, p(a+1), \eta, z_{a+1}), V_{a+1}^{Work}(j^P, j_a^C = 1, A_{a+1}, p(a+1), \eta, z_{a+1})]
\end{aligned}
$$

where $j_a^C = 1$ denotes completed basic education.

In the first period of adult life the child is in pre-school. Child education is normalized to zero. The parent solves the following maximization problem:

$$
\begin{aligned}
V_{\underline{a}}(j^P, A_{\underline{a}}, p(\underline{a}), \eta, z_{\underline{a}}) &= \max_{c_{\underline{a}}} \left\{U(c_{\underline{a}}) + \beta E_{z_{\underline{a}+1}} V_{\underline{a}+1}(j^P, A_{\underline{a}+1}, p(\underline{a}+1), \eta, z_{\underline{a}+1})\right\} \\
s.t. \qquad c_{\underline{a}} &= A_{\underline{a}}(1+r) + w_{jP,\underline{a}} - A_{\underline{a}+1}
\end{aligned}
$$

Step 4. Compute the new initial guesses for $W_{\underline{a}}^{Sch}(.)$ and $W_{\underline{a}}^{Work}(.)$.

The solution of the model in steps two and three provides the complete set of value functions and optimal saving rules for any combination of the state space variables. The optimal value function in the first period of adulthood, $V_{\underline{a}}$, provides a new initial guess for child lifetime utility. Denoting with $j_{\overline{a}}^C$ the level of education of the child at the end of the last period of coresidence, $V_{\underline{a}}(j^P = (j^C_{\overline{a}} + 1), A_{\underline{a}}, p(\underline{a}))$ provides the new initial guess for $W^{Sch}_{\underline{a}}(.)$ and $V_{\underline{a}}(j^P = j^C_{\overline{a}}, A_{\underline{a}}, p(\underline{a}))$ provides the new initial guess for $W^{Work}_{\underline{a}}(.)$. Given the new initial guesses for $W^{Sch}_{\underline{a}}(.)$ and $W^{Work}_{\underline{a}}(.)$, I repeat steps two and three above.

Given the conditional value functions for the work and schooling alternative, the child is sent to school when the expected value of investing in schooling is at least as high as the expected value of sending the child to work, that is when the following condition holds:

$$V^{Sch}_a(j^P, j^C_a, A_a, p(a), \eta, z_a) \geqslant V^{Work}_a(j^P, j^C_a, A_a, p(a), \eta, z_a) \quad \forall \quad a = a\_ed, ...\overline{a}$$

where a_ed denotes parental age when child education becomes a choice variable.

Step 5. Repeat steps two to four until the following two conditions are satisfied:

$$\begin{aligned} ||V^{Sch\_Iter}_{\underline{a}}(j^P, A_{\underline{a}}, p(\underline{a}), \eta, z_{\underline{a}}) - V^{Sch\_(Iter-1)}_{\underline{a}}(j^P, A_{\underline{a}}, p(\underline{a}), \eta, z_{\underline{a}})|| &\leq \varepsilon \\ ||V^{Work\_Iter}_{\underline{a}}(j^P, A_{\underline{a}}, p(\underline{a}), \eta, z_{\underline{a}}) - V^{Work\_(Iter-1)}_{\underline{a}}(j^P, A_{\underline{a}}, p(\underline{a}), \eta, z_{\underline{a}})|| &\leq \varepsilon \end{aligned}$$

where ε is an arbitrarily small number and $||.||$ denotes the distance between the conditional value functions in the first period of adulthood in two consecutive iterations.

Step 6. Compute the equilibrium skill prices as marginal productivities of the human capital factors using the equilibrium conditions set in equations (12) to (14).

Compute a new guess for the vector of the skill prices as a linear combination of the guess used to solve the model and the equilibrium prices computed in this iteration.

Step 7. Repeat steps two to six with the new guess for the vector of the skill prices.

Stop when the difference between each element of the vector of the equilibrium skill prices and the initial guess for this price is arbitrarily small.

Appendix C - Estimation and calibration

This Appendix gives details of the estimation of the wage equations and the production function and of the model's calibration.

Wage equations

Given the estimation of the fixed effect regression (21), I can treat as observable the following:

$$z^i_{j,qr} = \ln w^i_{j,qr} - g_j(age^i_{qr}) - \ln w_{j,qr} - \eta^i \tag{30}$$

I use the residuals from the wage equation to obtain an estimate of the distribution of the idiosyncratic shock. I assume that $z_{j,qr}$ is a normally distributed i.i.d. shock with mean zero and variance $\sigma^2_{z_j}$. I use the second moment of the distribution of $z_{j,qr}$ for each education group to parametrize the distribution of z in the model. For 1987 I find $\widehat{\sigma}^2_{z_1} = 0.065$, $\widehat{\sigma}^2_{z_2} = 0.07$, $\widehat{\sigma}^2_{z_3} = 0.079$. Table 5 presents the estimated variances for each year of the sample between 1987 and 2002.

Finally, the coefficients of the quadratic polynomials $g_j(age^i_{qr})$ provide the estimates of the education-specific experience effects in quarter qr. Table 6 presents the (yearly rescaled) estimates of the age and age squared term for each education group and year between 1987 and 2002.

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 5: Estimation Wage Equations: Variance of the Residuals (Source: ENEU)

Figure 5 presents the empirical frequencies of η obtained for 1987, the first year of the sample. The first and second moment of the distribution of η are used to parametrize the

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 6: Estimation Wage Equations: Age Polynomials (Source: ENEU)

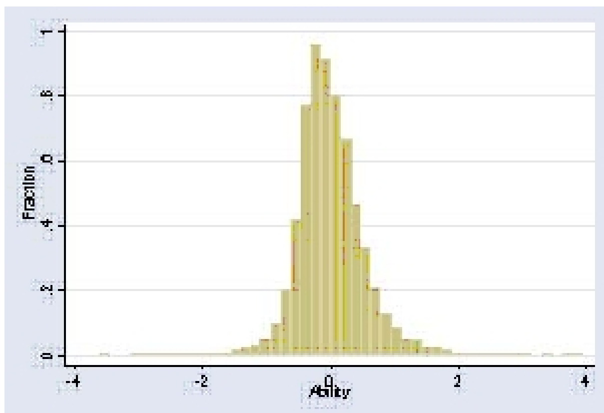


Figure 5: Estimation of the Wage Equations: Ability Distribution in 1987 (Source: ENEU)

initial distribution of ability. I find $\widehat{\sigma}_\eta^2 = 0.25$ and $\widehat{\mu}_\eta = 0$.

Production function

Panel A and B in Figure 6 report the total number of workers and the wage bills by level of education for each year between 1987 and 2002. The drop of the wage bills between 1994 and 1996 is the result of the Peso crisis that hit Mexico in 1994: the total wage bill declined in real terms by around 29 per cent at basic education and by around 35 and 48 per cent at intermediate and higher education. Wages started increasing again steadily for all education levels from the end of the 1990s.

Panel A and B in Figure 7 present the series of the estimated skill prices and human capital stocks normalized to 1987. As in the aggregate wage bills, the impact of the Peso crisis does also show up in the skill prices: between 1994 and 1996 the log skill price decreased by around twelve per cent at basic and by around ten per cent at intermediate and higher education.

Figure 6: Total Number of Wage Workers and Total Wage Bills by Level of Education in Mexico (Source: ENIGH)

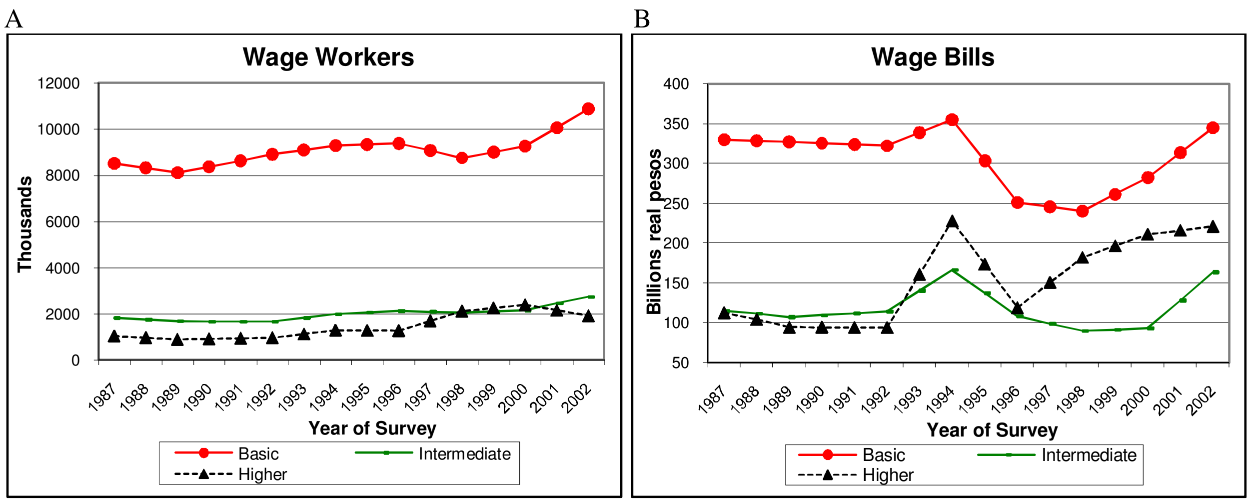
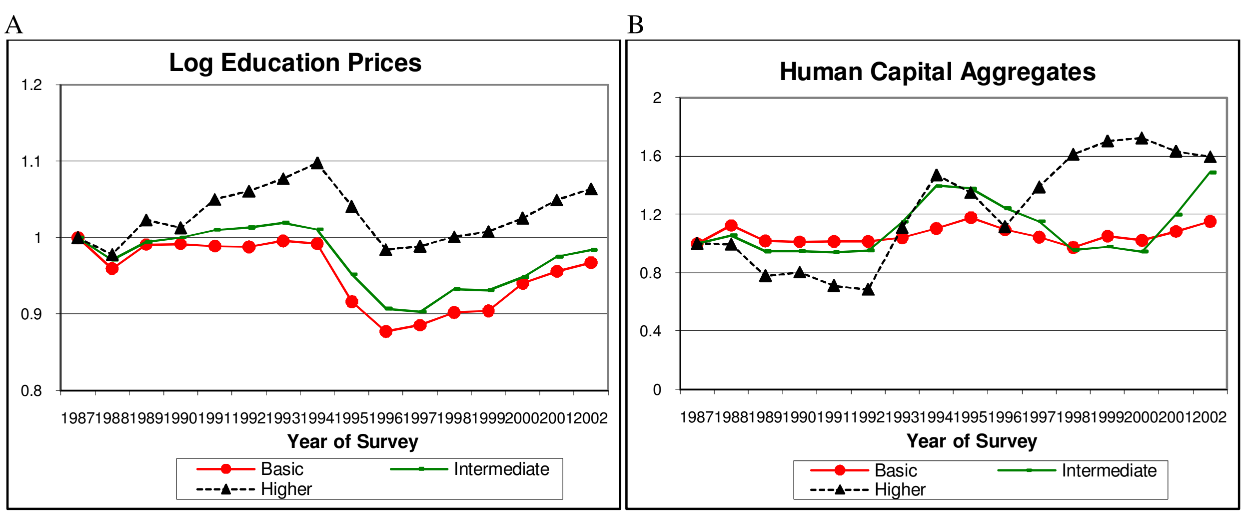


Figure 7: Estimated Log Skill Prices and Human Capital Aggregates in Mexico Normalized to 1987 (Source: author's calculations based on ENIGH and ENEU data)



Calibration

Figure 8 reports the complete list of the calibrated parameters together with their value, a brief description and the target used to calibrate the model.

Figure 8: Model's Calibration

Parameter	Value	Description	Target
t	7 years	Model period	Average length working life of adult Mexican workers
r	0.41	Real interest rate	Average real interest rate US 6-months Treasury Bills 1990-2000
β	0.71	Discount factor	1/(1+r)
γ	0.9	Relative risk aversion	Elasticity of intertemporal substitution estimated for LACs (Arrau and Wijnbergen, 1991)
B	0	Limit on net indebtedness	Maximum level of credit constraints
λ	1	Parental altruism	Parent-child dynasties linked by fully altruistic preferences
α	0.35	Share physical capital in production	Share physical capital estimated for LACs in the 1990s (Harrison, 1996 and Hoffman, 1993)
F_1	0.035	Fixed cost basic education	Proportion workers aged 25-60 with basic education in ENEU 1987
F_2	0.26	Fixed cost intermediate education	Proportion workers aged 25-60 with intermediate education in ENEU 1987