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On Skill Heterogeneity, Human Capital, and Inflation

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Abstract

This paper examines the welfare costs of inflation within a monetary dynamic general equilibrium framework with human capital that incorporates endogenous, ex ante skill heterogeneity among workers. Numerical experiments indicate that, overall, welfare costs are more likely to decrease with increases in skill heterogeneity. An implication of this feature is that a greater degree of skill heterogeneity may be associated with a higher tolerance for inflation, consequently implying a positive correlation between agent heterogeneity and inflation. Using a panel of several countries we empirically test this proposition. Our evidence lends some support to this hypothesis.

JEL classification codes: E52, E21, E27

1. Introduction

The impact of agents' heterogeneity on the macroeconomic performance of an economy is central to a large and growing body of literature, and remains an open area of research. However, both in the inequality-growth literature and in the inequality-inflation literature, researchers have often focused on one aspects of agents' heterogeneity, namely *income inequality* (e.g., Dolmas et al., 2000; Bhattacharya et al., 2003; Albanesi, 2000).

In common with some of the literature discussed above, this paper also explores the link between heterogeneity and inflation. However, the focus of this paper is on a different dimension of heterogeneity – viz. the heterogeneity in skill associated with structural features of the economy. The shift of focus from income inequality to skill heterogeneity is motivated by the literature that emphasizes the link between the deep structural (e.g., technological) parameters and economic growth (see for example Klump and Preissler (2000) and Turnovsky (2002)).

Specifically we study the link between agents' heterogeneity and inflation in the framework of an equilibrium model with ex-ante heterogeneity of the type studied in Kydland (1984, 1995) and Prasad (1996), with money introduced via a cash-in-advance constraint on the purchases on consumption. In our model an important parameter inversely representing ex-ante heterogeneity is the elasticity of substitution between skilled and unskilled effort. Differently from previous work in our model skill-heterogeneity is endogenous and depends on the extent of human capital accumulation undertaken by the representative household. We numerically compute the welfare-costs of inflation associated with variation in the heterogeneity-related parameters of the model.

One important result of this analysis is that the welfare costs of inflation are likely to *decrease* as skill heterogeneity increases. The impact of inflation in cash-in-advance models involves substitution out of activities subject to the inflation tax such as work effort, towards leisure. Low substitutability/higher heterogeneity entails a greater degree of investment in human capital, as output is more efficiently produced by using lower quantities of both skilled and unskilled effort. Since the welfare costs essentially derive from the compensation in consumption required to equate utilities under the optimal policy and the inflationary policy, the increase in leisure ensures that the compensation required is smaller as heterogeneity decreases.

Consequently, one would expect that economies with more heterogeneity will have a greater tolerance for inflation, implying a positive heterogeneity-inflation correlation in the data.

The second part of the paper tests the implications of our model, i.e. the implication that agents' heterogeneity indeed affects the policy maker's decision over the optimal inflation level. The choice of our measure of heterogeneity is based on numerical experiments which indicate a link between the ex-ante heterogeneity parameters of the model and other, more observable dimensions of heterogeneity, such as the skill-composition of the work force. Using inflation data from the International Financial Statistics published by the International Monetary Fund we compare the experiences of a number of countries over a period of time starting in 1960 and ending, in our most comprehensive case, in 2000. After controlling for differences in institutional arrangements across countries as in Cukierman and Webb (1995) we find that the implications of our model are broadly consistent with the empirical evidence on inflation and human capital heterogeneity.

The remainder of the paper is organized as follows. In Section 2 we describe the economic environment, and in Section 3 we briefly analyze the steady state. The model is parameterized in Section 4. The key implication of the quantitative experiments conducted in Section 4 is that welfare costs of inflation are inversely related to the degree of heterogeneity. In Section 5 we test this implication using a panel of a number of countries. Section 6 concludes.

2. The Economic Environment

The economy is populated with a continuum of identical, infinitely lived households that are uniformly distributed along the unit interval [0, 1]. As in Kydland (1984, 1995), we assume that each household consists of two types of workers, skilled (type 1) and unskilled (type 2). However, we make the further assumption that the productivity of the type 1 worker is endogenously determined by the household's skill accumulation, as we will describe later. Household preferences are given by

$$E\sum_{t=0}^{\infty}\beta^{t}u(c_{t},1-n_{1t},1-n_{2t}) \tag{1}$$

where c_t represents household consumption in time *t*, and n_{it} represents labor effort at time *t* of type *i* agent, *i*=1, 2. The functional form used for the momentary utility function is of the "indivisible labor" form as in Hansen (1985) and is given by

$$\log c_t - \psi\, a\, n_{1t} - (1-\psi)\, a\, n_{2t} \tag{2}$$

where ψ and $1-\psi$ are the underlying weights assigned to the leisure of skilled and unskilled workers respectively.[1]

Households enter period t with nominal money balances m_{t-1}, carried over from the previous period. The government augments these money balances by a lump-sum transfer equal to the increase in money supply, where the aggregate money supply M_t is determined according the following rule:

$$M_t = g_t M_{t-1}. \quad (3)$$

Thus the total amount of money balances held by a household at the beginning of period t is the amount

$$m_{t-1} + (g_t - 1)M_{t-1}. \quad (4)$$

To ensure that money is valued in equilibrium, we assume the presence of a cash in advance constraint on the purchase of the non-storable consumption good. Expenditure on the consumption good, therefore cannot exceed the total money balances available to the household, i.e.,

$$p_t c_t \le m_{t-1} + (g_t - 1)M_{t-1}. \quad (5)$$

The growth rate of money, g_t, evolves according to:

$$\log(g_{t+1}) = \gamma \log(g_t) + \xi_{t+1}. \quad (6)$$

ξ_{t+1} is *i.i.d* normal with mean $(1-\gamma)\log(\overline{g})$ and variance σ_ξ^2 and $\log(\overline{g})$ represents the unconditional mean of $\log(g_t)$.

In every period t, household expenditures consist of consumption (c_t), investment in physical capital (x_t), investment human capital (s_t), and the amount of money balances $\left(\frac{m_t}{p_t}\right)$ that are to be carried over to the next period. These expenditures must not exceed total household income, which is the sum of income earned from skilled and unskilled labor, capital, money balances carried over from the previous period, and the lump-sum monetary transfer from

[1]Specifically skilled and unskilled workers can work some given positive number $h < 1$ or not at all, implying household consumption sets are non convex. However, as in Hansen (1985) and Rogersen (1988), the household consumption set is made convex by allowing agents to trade employment lotteries. As in Prasad (1996), this economy has two independent employment lotteries, one for skilled workers and another for unskilled workers. The expected utility of each household is then defined over total household consumption and the probability of employment of each type of worker.

the government. Households therefore maximize expected lifetime utility subject to (5) and a sequence of budget constraints of the following form:

$$c_t + x_t + s_t + \frac{m_t}{p_t} \leq w_{1t}n_{1t} + w_{2t}n_{2t} + r_t k_t + \frac{m_{t-1} + (g_t - 1)M_{t-1}}{p_t}, \qquad (7)$$

where household investment expenditure for physical and human capital in period-*t* is respectively given by

$$x_t = k_{t+1} - (1-\delta_k)k_t; \qquad (8)$$

$$s_t = h_{t+1} - (1-\delta_h)h_t. \qquad (9)$$

In equation (8) k_t and h_t respectively denote the household's physical and human capital stock in period-*t*; δ_k and δ_h are the corresponding rates of depreciation.

The representative firm in this economy takes the average skill accumulation by the households as given, and hires labor N_t and physical capital K_t to produce

$$Y_t = e^{z_t} K_t^{\theta} N_t^{1-\theta} \qquad (10)$$

where z_t is an exogenous productivity shock, that follows an AR(1) process of the form:

$$z_{t+1} = \rho z_t + \varepsilon_{t+1}, \qquad 0 < \rho < 1. \qquad (11)$$

Here ε_{t+1} is *i.i.d* with zero mean and constant variance σ_z^2.

In (10), the aggregate time-t labor input N_t is a CES function of skilled and unskilled labor, given by

$$N_t = \left\{\omega(h_t)N_{1t}^{1-\nu} + N_{2t}^{1-\nu}\right\}^{\frac{1}{1-\nu}}. \qquad (12)$$

The elasticity of substitution between the two types of labor is given by $\frac{1}{\nu}$. The function $\omega(h_t)$ captures the productivity of skilled labor, which is assumed to be increasing and concave, with $\omega(0) = 1$. Note that the degree of heterogeneity in this model is reflected in two parameters: a parameter that impacts directly on the skill differential between the two types of labor effort considered $\omega(h_t)$, and a parameter that describes the elasticity of substitution between them, namely $\frac{1}{\nu}$.

In addition, we make the assumption that the economy wide average stock of human capital equals the stock of human capital accumulated by the household, i.e., $h_t = H_t$.[2] The representative household therefore indirectly influences the relative wage rates of skilled and unskilled labor and the rental rate of capital through its choice of human capital accumulation.

Taking that choice as given, the firm maximizes profits, which are equal to $Y_t - w_{1t}N_{1t} - w_{2t}N_{2t} - r_t K_t$. The optimality conditions for the firm's problem yield the following functions for the skilled and unskilled wage rates, and the rental rate for capital:[3]

$$w_{1t}(z_t, K_t, N_{1t}, N_{2t}) = 1-\theta)e^{z_t} K_t^{\theta} N_t^{\nu-\theta} \omega(h_t) N_{1t}^{-\nu} \tag{13}$$

$$w_{2t}(z_t, K_t, N_{1t}, N_{2t}) = (1-\theta)e^{z_t} K_t^{\theta} N_t^{\nu-\theta} N_{2t}^{-\nu} \tag{14}$$

$$r_t(z_t, K_t, N_{1t}, N_{2t}) = \theta e^{z_t}\left(\frac{K_t}{N_t}\right)^{\theta-1}. \tag{15}$$

For a value of g greater than one, both M_t and p_t will grow without bound. In order to make the household's problem stationary, some of the variables need to be transformed. To that end, we define $\hat{m}_t = \frac{m_t}{M_t}$ and $\hat{p}_t = \frac{p_t}{M_t}$. We can then state the household's problem as follows:

$$\max_{c_t, n_{1t}, n_{2t}, \hat{m}_t, k_{t+1}, h_{t+1}} E_0 \sum_{t=0}^{\infty} \beta^t \left\{\log(c_t) - \psi a\, n_{1t} - (1-\psi) a\, n_{2t}\right\} \tag{16}$$

subject to

$$\frac{\hat{m}_t}{\hat{p}_t} + c_t + k_{t+1} - (1-\delta_k)k_t + h_{t+1} - (1-\delta_h)h_t = w_{1t}n_{1t} + w_{2t}n_{2t} + r_t k_t + \frac{\hat{m}_{t-1} + g_t - 1}{\hat{p}_t g_t}, \tag{17}$$

$$c_t = \frac{\hat{m}_{t-1} + g_t - 1}{\hat{p}_t g_t} \tag{18}$$

the process for technology and monetary shocks, the aggregate capital accumulation rule, given by,

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[2] With the exception of skill accumulation, capital letters denote aggregate economy wide per capita variables which an individual household regards as being outside its sphere of influence, while lower case letters denote variables specific to the household.

[3] Since the aggregate production technology is of the Cobb-Douglas form, profits will be zero in equilibrium, even though aggregate labor effort is a CES function of skilled and unskilled labor. This is easily verified by substituting the optimal wage and rental rates in the profit function.

$$z_{t+1} = \rho z_t + \varepsilon_{t+1}, \quad (19)$$

$$\log(g_{t+1}) = \alpha \log(g_t) + \xi_{t+1}, \quad (20)$$

$$K_{t+1} = (1-\delta)K_t + X_t, \quad (21)$$

as well as the economy-wide aggregate decision rules perceived by the households:

$$N_t = N(z_t, g_t, K_t),$$

$$X_t = X(z_t, g_t, K_t),$$

and,

$$\hat{P}_t = \hat{P}_t(z_t, g_t, K_t). \quad (22)$$

In equilibrium, aggregate per capita quantities turn out to be equal to the choices of the representative household. In particular, it must be the case that $n_t = N_t$, $k_t = K_t$, $x_t = X_t$, and $\hat{m}_{t-1} = \hat{m}_t = 1$. Since the cash in advance constraint is assumed to be binding in equilibrium, we also have $c_t = \frac{1}{\hat{P}_t}$.

3. The Steady State

In this section we show that, since money is introduced in our model via a cash-in-advance constraint, inflation has a negative has impact on the long-run outcomes of several variables, as is typically expected of such models. Furthermore, consistent with some of the theoretical literature on the link between inflation and human capital, we find that inflation has a negative impact on human capital accumulation.[4] The degree of skill heterogeneity in our model has a further impact on the magnitude of distortions associated with inflation, as suggested by some of the analytical results of this section. The subsequent section, based on numerical experiments in fact indicates that it tends to weaken them. Consequently, the welfare costs of inflation tend to decrease with an increase in heterogeneity.

From the first order conditions (I.1)-(I-7) with respect to $c_t, n_{1t}, n_{2t}, \hat{m}_t, k_{t+1}, h_{t+1}$ (reported in Appendix I) a non-stochastic steady state emerges where the endogenous variables of interest such as consumption and work effort are expressed as function of human capital. Manipulating (I.1)-(I.4) and (I.6) we can express other variables such as consumption and work-effort as functions of human capital:

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[4]For a survey, see Gillman and Kejak (2005).

$$C = \frac{(1-\theta)\beta\kappa^{\theta}(\phi(H))^{\nu}\,\omega(H)}{\psi\, a\, g}, \tag{23}$$

$$N_1 = \frac{\frac{1}{\beta} - 1 + \delta_h}{\frac{1-\theta}{1-\nu}\kappa^{\theta}(\phi(H))^{\nu}\,\omega'(H)}, \tag{24}$$

$$N_2 = \left(\frac{\psi}{(1-\psi)\omega(H)}\right)^{\frac{1}{\nu}} \frac{\frac{1}{\beta} - 1 + \delta_h}{\frac{1-\theta}{1-\nu}\kappa^{\theta}(\phi(H))^{\nu}\,\omega'(H)}, \tag{25}$$

$$N = \frac{\phi(H)\left(\frac{1}{\beta} - 1 + \delta_h\right)}{\frac{1-\theta}{1-\nu}\kappa^{\theta}(\phi(H))^{\nu}\,\omega'(H)}, \tag{26}$$

$$K = \kappa^{\theta} N = \frac{\phi(H)\left(\frac{1}{\beta} - 1 + \delta_h\right)}{\frac{1-\theta}{1-\nu}(\phi(H))^{\nu}\,\omega'(H)}. \tag{27}$$

In the above equations $\phi(H) = \left[\omega(H) + \left(\frac{\psi}{(1-\psi)\omega(H)}\right)^{\frac{1-\nu}{\nu}}\right]^{\frac{1}{1-\nu}}$. Also note that for an interior solution to work effort, we need to impose $\nu < 1$. Making the necessary substitutions in (I.7) we can then derive an implicit equation in human capital, given by:

$$\frac{(1-\theta)\beta\kappa^{\theta}(\phi(H))^{\nu}\,\omega(H)}{\psi\, a\, g} + \delta_h H = \frac{(\kappa^{\theta} - \delta_k \kappa)\left(\frac{1}{\beta} - 1 + \delta_h\right)}{\frac{1-\theta}{1-\nu}\kappa^{\theta}(\phi(H))^{\nu}\,\omega'(H)}. \tag{28}$$

We are interested in understanding how inflation impacts upon accumulation of human capital H. Clearly total differentiation of the above equation with respect to H and g yields a fairly complicated expression for $\frac{dH}{dg}$:

$$\frac{dH}{dg}=\frac{\dfrac{\Delta_1\left(\phi(H)\right)^{2\nu}\omega(H)\omega'(H)}{g^2}}{\dfrac{\Delta_1}{gH}\left(\phi(H)\right)^{2\nu}\omega(H)\omega'(H)\left\{2\nu\Omega_\phi+\Omega_\omega-\Omega_{\omega'}\right\}+\delta_h(\phi(H))^{\nu}\omega'(H)\left\{1+\nu\Omega_\phi-\Omega_{\omega'}\right\}}. \quad (36)\,(29)$$

In (29) we define $\Delta_1=\dfrac{(1-\theta)\beta\kappa^\theta}{\psi a}$. Also we can identify a few elasticities, namely, $\Omega_\phi=H\dfrac{\phi'(H)}{\phi(H)}$, $\Omega_\omega=H\dfrac{\omega'(H)}{\omega(H)}$, $\Omega_{\omega'}=-H\dfrac{\omega''(H)}{\omega'(H)}$, where the expressions $\phi'(H)$ and $\omega'(H)$ are partial derivatives of the respective functions with respect to *H*.[5] Clearly, since the sign of the denominator is ambiguous, how inflation impacts on consumption, work effort, physical and human capital is difficult to discern analytically. Nevertheless, if we impose some restrictions to ensure that $\dfrac{dH}{dg}$ is negative, it is possible to derive some weak analytical results, which will make it somewhat easier to analyze and interpret the results based on numerical experiments in the subsequent section.

We can then summarize our analysis of equations (29) and (23)-(27) in the following propositions, the proof of which is presented in Appendix II:

Proposition 1: Let the following assumptions hold:

(a): $\phi'(H)>0$,

(b): $\dfrac{\Delta_1}{gH}\left(\phi(H)\right)^{2\nu}\omega(H)\omega'(H)\left\{2\nu\Omega_\phi+\Omega_\omega-\Omega_{\omega'}\right\}+\delta_h(\phi(H))^{\nu}\omega'(H)\left\{1+\nu\Omega_\phi-\Omega_{\omega'}\right\}<0$.

Then

(i) steady state human capital investment is decreasing in the rate of inflation, i.e. $\dfrac{dH}{dg}<0$;

(ii) steady state consumption is decreasing in the rate of inflation, i.e., $\dfrac{dC}{dg}<0$.

[5] For example, note that $(N/N_1)=\phi(H)$. Then $\phi(H)$ can be regarded as the average contribution of skilled effort to aggregate effort. Consequently, we can interpret Ω_ϕ as the elasticity of this average contribution to changes in human

Proposition 2: If the conditions of Proposition 1 hold and $\Omega_{\omega'} > \nu\Omega_{\phi}$,

(i) steady state skilled effort is decreasing in inflation, i.e. $\frac{dN_1}{dg} < 0$;

(ii) the sign of $\frac{dN_2}{dg}$ is ambiguous;

(iii) steady state aggregate effort is decreasing in inflation, i.e. $\frac{dN}{dg} < 0$;

(iv) the steady state capital stock is decreasing in inflation, i.e. $\frac{dK}{dg} < 0$.

Note that in Proposition 1 the condition $\phi'(H) > 0$ requires that the average contribution of skilled effort to the "aggregate" work effort in this economy responds positively to changes in human capital accumulation. Assumption (b) simply ensures that human capital responds negatively to inflation. In Proposition 2, the additional condition requires that the elasticity of the return to human capital investment be greater than the human capital elasticity of the average contribution of skilled effort to aggregate effort, multiplied by the factor ν, which is the inverse of the elasticity of substitution between the two types of labor. One can perhaps interpret the above Propositions as stating conditions under which inflation-tax distortions, as measured by the negative impact of inflation on human capital, skilled effort, and consumption, etc. are important.

The intuition for the negative impact of inflation on economic aggregates is straightforward, and common to several cash-in-advance models in the literature. Inflation acts as a tax on consumption since it requires the use of cash. This leads economic agents to substitute consumption for activities that do not require the use of cash, such as leisure. The decline in work effort causes a decline in output, and consequently consumption, investment and the physical and human capital stock. However, it is also intuitively clear that the *magnitude* of the negative response to inflation in this economy is likely to be affected significantly by the parameters of the functions $\omega(H)$ and $\phi(H)$. Specifically, varying ν, ψ or α, which can be interpreted parameters affecting the extent of ex ante heterogeneity in this economy, has an

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capital investment. Ω_{ω} is the elasticity of the return to human capital to changes in human capital investment, and $\Omega_{\omega'}$ is elasticity of the *marginal* return to human capital to changes in human capital investment.

impact on the conditions of Propositions 1 and 2, and consequently the magnitude of the distortions associated with inflation. Also note that the conditions in the above propositions are only *sufficient* conditions for the response of human capital, consumption, and other variables to be negative. Keeping this mind, in the next section we perform numerical experiments and we will use the conditions of Propositions 1 and 2 to assist in the interpretation of our results.

4. Inflation and Skill Heterogeneity: Results Based on Quantitative Experiments

In this section, we explore the relationship between inflation and heterogeneity by examining how long-run aggregate outcomes and welfare costs of inflation change as we vary the levels of the parameters that capture heterogeneity. We consider two dimensions of skill-heterogeneity. One is the composition of the work-force $\frac{N_1}{N_1 + N_2}$. If this ratio is close to 50%, there is more heterogeneity in the sense that both types of labor are equally represented in the population. The other dimension is the magnitude of $\omega(H)$ - larger values represent a greater skill differential and consequently greater heterogeneity. Interestingly, although these dimensions respond very dramatically as one varies the heterogeneity parameters ν and α, the impact of changing the inflation parameter g on these dimensions is negligible. It is important to keep this result in mind particularly to fully appreciate the way we solve the identification problem in the econometric testing of our model's implications in Section 5.

Before proceeding we specify $\omega(H) = 1 + H^{\alpha}; \quad 0 < \alpha < 1$, so that the parameters relevant to the degree of heterogeneity are $\alpha, \psi,$ and ν. For all these and the remaining parameters of the model we refer to Table III.1 in Appendix III, which provides the range of variation of each parameter and the relevant literature that motivates such a choice of range. The numerical procedure used to calculate the steady state is described in Appendix III. To compute welfare costs of inflation, we calculate the increase in consumption that an individual would require to be as well off under the equilibrium allocation associated with the optimal monetary policy.[6] We calculate this loss, expressed as a percentage of output and also of consumption, for varying levels of each of the heterogeneity parameters. Note that since ψ is a preference parameter, it

[6] Specifically, we solve for *x* in the equation $\overline{U} = \log(c^*(1+x)) - \psi n_1^* - (1-\psi) n_2^*$, where c^*, n_1^*, n_2^* are levels of consumption and work effort associated with monetary policy that sets $g > 1$, while $\overline{U}$ is the utility attained under the optimal policy which sets $g = \beta$.

obviously affects the *measure* of welfare costs itself. An experiment that considers the effects of varying ψ on welfare costs of inflation is therefore inappropriate.

Table 1 below presents the steady state values of variables and associated welfare costs of inflation as the monetary growth rate increases, with the heterogeneity parameters fixed at $\alpha = 0.05; \nu = 0.1; \psi = 0.59$. Figures 1(a) and 1(b) present the steady state values of variables as ν increases. The 'x' line represents the policy with inflation ($g = 1.15$) and the dotted line represents the optimal policy ($g = \beta$). Figure 1(c) presents welfare costs of inflation as ν increases. Figures 2(a) and 2(b) present the percentage difference in the steady state values of variables in the presence of inflation, relative to their steady state levels when $g = \beta$, for different values of ν. Figure 2(c) presents the elasticity $\Omega_{\omega'}$ and the weighted elasticity $\nu\Omega_{\phi}$ for different values of ν, where the '*' line represents the latter. Figures 3(a)-(c) and Figures 4(a)-(c) present similar experiments with the parameter α.

First, we examine the computations presented in Table 1. The heterogeneity related parameters in this case are fixed at $\alpha = 0.05; \nu = 0.1; \psi = 0.59$, and the monetary growth rates are set at $g = \beta$, $g = 1.024; g = 1.05;$ and $g = 1.15$. The usual features of cash-in-advance models are apparent: inflation impacts negatively on consumption, work effort, physical and human capital, and output. [7] In a quantitative sense, the magnitudes of welfare costs are higher than would be observed in a model without endogenous skill heterogeneity or human capital, such as in Cooley and Hansen (1989). However, the impact of inflation on certain dimensions associated with heterogeneity is relatively small. For example the impact of inflation on the skill-composition of the workforce as represented by the ratio $N_1/(N_1 + N_2)$, and the skill differential $\omega(H)$ is negligible relative to other variables.

Next we examine the effects of varying the heterogeneity parameters and how this variation impacts on the magnitude of distortions associated with inflation. First consider Figures 1(a) and (b). The response of variables to changes in ν appears similar regardless of the monetary policy in operation, and the magnitude of the negative impact of inflation does not look very striking. The magnitude of the inflation-tax distortions is, however, difficult to discern from these figures and we therefore defer the discussion of these distortions until the analysis of Figures 1(c) and

[7] In a qualitative sense, these results hold for other combinations of the heterogeneity parameters as well.

Figures 2(a) and (b).[8] First, we attempt to gain some intuition for how changes in ν affect the long run values of economic aggregates in general, regardless of what the inflation rate is. Increasing ν, which is the inverse of the elasticity of substitution between different types of labor, amounts to increasing skill heterogeneity in this economy along two dimensions. One dimension is associated with the falling elasticity of substitution – heterogeneity increases in the sense that the two types of labor are substitutable to a lower degree in the production process. Secondly, it is clear from Figure 1(a) that the equilibrium composition of the work force becomes more heterogeneous as ν increases. For high substitutability (and low ν) the work force comprises almost entirely of the skilled type of labor, but as the elasticity of substitution drops, (ie. ν increases) the work force becomes more heterogeneous. Also, lower substitutability encourages investment in human capital; to the extent that the more expensive type of effort is used, it would be more economical to employ it if its marginal return were higher – and human capital accumulation ensures this. This is also reflected in the increasing skill differential as ν increases. Higher levels of human capital increase the overall productivity of all inputs, and consequently, more of both types of labor are employed at a higher wage rate. Higher productivity also encourages physical capital accumulation. As a result, output and consumption also increase.

So far, we have not considered how inflation-tax distortions are affected as ν increases. From Figures 1(a) and (b) it is easy to discern the negative impact of inflation we discussed earlier. However, we cannot comment on the magnitude of these distortions until we discuss the percentage differences in the levels of variables relative to the case in which the optimal policy prevails. These differences are shown in Figures 2(a) and (b), which clearly indicate an increase in the magnitude of inflation tax distortions as ν increases. However, before we discuss Figure 2, we consider the overall measure of inflation tax distortions, as represented by the welfare cost of inflation defined earlier. Figure 1(c) presents such welfare cost computations for different values of ν. It is clear that the welfare cost of inflation, relative to both consumption as well as output decreases as ν increases. In other words, welfare costs of inflation decrease as heterogeneity increases.

[8] The size of the differences is relatively small in comparison to the length of the scale of the vertical axis in all of the graphs. However, as will become clear from the analysis of percentage deviations relative to the optimal policy, presented in Figures 2(a) and (b), these differences can be quite significant.

To explain why the welfare costs of inflation decrease as ν increases, we resort to a somewhat heuristic explanation based on Figure 2(a). Recall that our measure of welfare costs is based on a consumption-compensation that equates the utility under the distortionary policy to the utility associated with the optimal policy. However, utility depends on both consumption and leisure – and it is clear that while consumption relative to the optimal policy decreases as ν increases, leisure of both types increases relative to the optimal policy. Overall, the compensation required to equate utilities falls as ν increases.

A more intuitive explanation rests on some of the conditions of Propositions 1 and 2 in the previous section. The assumptions $\phi'(H) > 0$, and $\Omega_{\omega'} > \nu\Omega_{\phi}$, appear as *sufficient* conditions for the impact of inflation to be negative. However, our simulations clearly demonstrate that these conditions are not *necessary* to ensure a negative impact of inflation on the variables of the model. Nevertheless, since the distortions appear to be larger in the range of values for ν in which $\phi'(H) > 0$, we can perhaps speculate that this condition may be of some relevance in interpreting the results.[9] In particular, given that $\phi(H) = N/N_1$, the condition $\phi'(H) > 0$ requires that the average contribution of skilled effort responds positively to changes in human capital accumulation. We know that inflation tax distortions are likely to increase leisure of both types as agents substitute out of consumption and work effort because of the inflation tax. However, as ν increases, substitution possibilities diminish and we would expect a larger decline in skilled effort relative to unskilled effort, particularly if the average contribution of skilled effort were to increase, as a smaller amount would be required to produce the same amount of output, and this would be the case if $\phi'(H) > 0$. This appears to be the case for larger values of ν, as is evident from Figures 2(a), (b), and (c).

We can also see that while the inflation tax distortions increase for all variables as ν increases, the increase is less rapid for many of the variables- viz. unskilled effort, capital, output, and productivity, at the higher end of values in the range considered. Again, we can speculate that the condition $\Omega_{\omega'} > \nu\Omega_{\phi}$ may have a bearing on the interpretation of this feature. The left hand side of this inequality represents the rate at which the marginal increase in the skill-differential, and consequently the skilled wage rate, decreases as human capital accumulates. The right hand

[9] Note that $\nu\Omega_{\phi} > 0 \text{ iff } \phi'(H) > 0$. This means that we can infer whether the latter condition holds from Figure 2(c).

side is the elasticity of the average skill contribution (weighted by the elasticity of substitution) to human capital accumulation. When the inequality holds, marginal costs of production are greater than the marginal benefits from production, and this discourages human capital accumulation to some degree, albeit the costs are increasing at a decreasing rate as a human capital increases. This enhances the inflation-tax distortions. When the right hand side is positive large and relative to the left hand side, the benefits are greater than the costs, and the relative impact of inflation tax effects increases at a diminishing rate.

A discussion of what happens when α is allowed to vary is reported in Appendix IV. It is also important to stress that the calibrated value of $\omega(H)$ in the literature is usually close to 2. Interestingly, this condition is satisfied when the deep parameter ν is allowed to change in our experiments, but it varies between 2 and 6 in experiments where α varies. This motivates our focus on experimental results when ν varies. We then proceed by calibrating α so that $\omega(H)$ is close to 2, so that the α simulations are not essential in informing our empirical section. Overall however, we are able to conclude that high levels of heterogeneity are likely to be associated with lower welfare costs of inflation. An implication of this result is that economies in which agents are characterized by a higher degree of heterogeneity experience lower costs of inflation, and as such are likely to experience higher inflation rates. In other words, skill heterogeneity could contribute toward explaining variations in the inflation experiences of different countries at any given point in time. The scope of the next section is to empirically estimate the correlation between inflation and skill heterogeneity.

5. Inflation and Skill Heterogeneity: An Empirical Analysis

In the previous sections a higher value of the deep parameter ν, a lower substitutability between skilled and unskilled labour (and a higher degree of skill heterogeneity between the two types of individuals in the representative household) reduces the welfare costs of inflation. These economies thus may reveal a higher tolerance for inflation.

The scope of this second part of the paper is to conduct an empirical analysis and look for econometric support to the model's prediction of a positive correlation between skill heterogeneity and inflation. In order to test whether agents' heterogeneity indeed affects the policy maker's decision over the optimal inflation level we compare the experiences of a number of countries over a period of time starting in 1960 and ending, in our most comprehensive case, in 2000. Our empirical strategy is to control for differences in institutional arrangements across countries so as to shed light on the correlation between human capital inequality and inflation. The data on inflation are drawn from The International Financial Statistics published by the International Monetary Fund. The sample comprises 108 countries, of which 33 are defined as developed economies (LDC = 0) and 44 are defined by Cukierman and Webb (1995) as democracies (dummy for authoritarian regime=0). However, the number of countries actually used in the estimation procedure is much smaller due to data availability constraints.

5.1 The Explanatory Variables: Measuring heterogeneity

A measure of workforce heterogeneity that appears to be consistent with the model, is the country-level skilled *versus* unskilled labour share in the workforce. Here we stress two important caveats regarding the use of the workforce skill heterogeneity. Firstly, in the model skill heterogeneity, as measured by $\frac{N_1}{N_1 + N_2}$, and inflation are not in a causal relationship. The positive correlation between the two is fundamentally driven by deep parameters, such as ν, the inverse of the elasticity of substitution between the two types of labour. The finding of a positive correlation between skill heterogeneity and inflation only provides an indirect test of the model's prediction. Obviously, a more suitable test would be to measure the deep parameter ν, which is difficult as a measure of ν necessarily reflect country-time-specific technologies that define the way skilled and unskilled labour substitute or complement each other in production.

Secondly, note that while there is a negative link between ν and $\frac{N_1}{N_1 + N_2}$, as shown in Figure 1(a), the skill ratio does not relate in the same way with the other parameter of heterogeneity α. (See figure 3(a)). However, we can simulate what the values of the skill ratio would be when both heterogeneity parameters vary simultaneously. Ideally $\frac{N_1}{N_1 + N_2}$ would be monotonically correlated with the deep parameters of heterogeneity α and ν in the model so to proxy deep heterogeneity in a well-defined way. The simulation results are the following:

```
nu=[0.1, 0.15, 0.225,0.3375];
alpha=[0.05, 0.075, 0.1125, 0.16875];
n1/(n1+n2))*100=[97.32, 93.48, 90.01, 91.33] for the optimal policy
g=beta;
n1/(n1+n2))*100=[97.21, 93.22, 89.56, 90.71] for the policy g=1.15;
welfare cost as percent of consumption=[10.61, 9.89, 8.24, 4.41];
welfare cost as percent of output=[2.76, 3.61, 3.22, 0.32];
```

They raise two considerations: If nu and alpha are independent from each other, the numerical information provided above combined with the simulated link between the skill ratio and ν (figure xxx) tells us that alpha may have a positive impact on the skill ratio, which takes over the impact on ν on this ratio as α gets bigger. Thus for α large, $\frac{N_1}{N_1 + N_2}$ would correlate negatively with ν, but it would correlate positively with α. This is potentially a problem since ideally the skill ratio would move in the same direction as the two deep parameters measuring heterogeneity move.

Here it is important to stress that the numerical results above however indicate that in a wide range of values of ν [0.1,0.225] and α [0.05,0.1125], values for which deep heterogeneity increases the skill ratio $\frac{N_1}{N_1 + N_2}$ monotonically decreases (ex-post heterogeniety increases), while the welfare costs of inflation drops monotonically. Thus $\frac{N_1}{N_1 + N_2}$ is indeed a good proxy for ex-ante heterogeneity and empirically we should expect a positive relationship between inflation and skill diff. implied by theory and simulations.

To measure $\frac{N_1}{N_1 + N_2}$ data are drawn from the Barro and Lee "International Data on Educational Attainment: Updates and Implications" database, which is available from the url: www.cid.harvard.edu. Barro and Lee (1993) data set breaks down the population of each country into seven categories: no education, some primary, completed primary, some secondary, completed secondary, some higher, and completed secondary education. Caselli and Coleman (2006) examine three possible partitions of these seven sub-groups into an unskilled and a skilled aggregate, based on three different thresholds for 'skilled': *(i)* Basic literacy and numeracy threshold. Lu is an aggregate of workers with no education and with some primary education. Ls includes all other groups. *(ii)* Completed secondary schooling is the threshold. *(iii)* Completed college is the threshold.

In our empirical exercise we will use the following variables as explanatory variables for country level inflation: *skilledp1* (N1/(N1+N2) for partition 1); *skilledp2* (N1/(N1+N2) for partition 2); *skilledp3* (N1/(N1+N2) for partition 3); school (average years of schooling).

The type of heterogeneity at work in the theoretical model is correlated with agents' productivity, and affects the agents' substitutability in the production process. Differences in human capital attainment indeed produce heterogeneity that affects productivity, and the substitutability between agents in addition to the value assigned to non-working activities. Another candidate to measure skill heterogeneity is thus human capital inequality. Data for education Gini coefficient by country-year are provided by Castello and Domenech (2002). Using the recent information contained in Barro and Lee's (2001) data set about educational attainments, Castello and Domenech calculate a human capital Gini coefficient $G = 1 - 2\int_0^1 A(y)dy$ where $A(y)$ is the Lorenz curve of the educational attainment distribution. The Lorenz curve plots the cumulative percentage of educational attainment (human capital) reached by the bottom y-percent of the population. The Gini coefficient is a measure of human capital inequality that ranges from zero to one: in the case of perfectly equal distribution the Lorenz curve would coincide with the 45-degree lines and the Gini coefficient would be zero.

Castello and Domenech (2002) propose two Gini coefficients, namely G25, the Gini coefficient computed using the population aged 25 and plus, and G15, the Gini coefficient computed using the population aged 15 and plus. While for the most part we will use the former, we will use the latter to check the robustness of our results. Both measures of human capital inequality are available for all 108 countries in the data set at times of 5-year interval starting from 1960.

It is however important to emphasize that the use of the education Gini coefficient as a measure of skill heterogeneity in this model is problematic. In fact this coefficient is computed from the entire population rather than from the household. Thus its counterpart in the model is 0.5, regardless of any fundamental parameter values because in the model, half the population accumulates human capital, and they all accumulate the same level.

5.2 Other Explanatory Variables

It is now well established that the conduct of monetary policy and specifically the rate of growth of the money stock is the primary factor determining a country's inflation rate. The actual policy pursued by the monetary authority depends on a number of factors some of which have an exquisitely political flavor. For instance there is now a large body of literature that relates central banks' decisions to their independence from, or vulnerability to, political pressure, which may work to deviate the central bank's attention from the pursuit of a price stability goal (e.g., Cukierman, Webb and Neyapti, 1992; Cukierman and Webb, 1995). The other variables we include in our data set reflect this type of argument. The measures of Central Bank independence (CBI), central bank vulnerability (vulnerability) and political instability (political change) come from the Cukierman and Webb (1995) data set. The CBI variable measures legal independence of central bank from political power. Cukierman et al., (1992) code central bank independence following two main principles. First of all, they code only a few narrow but relatively precise legal characteristics. Secondly, they only use the written information from central banks' charters. The legal characteristics as described in the charters define a few important issues, namely:

(i) the appointment, dismissal and term of office of the central bank's chief officer;
(ii) the policy formulation cluster and the resolution of possible conflicts over monetary policy between monetary and fiscal authorities;
(iii) the objectives of the central bank;
(iv) limitations on the ability of the central bank to lend to the public sector and regulation of the modalities with which such lending can take place.
The way the single components of central bank's legal independence are aggregated is fully described in Cukierman et al., (1992).

The Cukierman-Webb (1995) vulnerability variable takes its origin from raw data on the actual dates of changes of the governors of the central banks. To measure central bank vulnerability to political instability, Cukierman and Webb estimate the probability per month of a change in central bank governor conditional on being a time interval that follows a political transition. They show that although this probability decreases monotonically with the number of months that have elapsed since the last political transition, the estimated probability of a change in governor at the central bank is more than two times larger in periods within six months after a political transition than in periods that are more removed from political change. They then compute an index of the political vulnerability of the central bank (vulnerability), defined for each country in the Cukierman-Webb (1995) sample as the fraction of political transitions that are followed with a lag of 0 to 6 months by a replacement of the central bank governor. Cukierman and Webb (1995) illustrate that the highest level of central bank vulnerability occurs in the face of high level political transitions, which is then included among the explanatory variables.

The last variable we include is the degree of openness (openness) of an economy to the rest of the world. We measure this as the ratio of the sum of imports and exports over a country's GDP. The argument is that the degree of exposure to international trade may increase the ability of a central bank to pre-commit to a given (low) inflation target.

The Cukierman-Webb variables described above are available for 67 countries from 1950 to 1989 although data for economies that achieved political independence or established a central bank after the 1950 start later. The Cukierman-Webb data set includes all the major industrial and developing economies, but excludes most Easter European countries. Table 2 reports the summary statistics for the main variables.

5.3 The Empirical Specification.

We estimate a model of the form

$$\pi_{it} = \alpha + x_{it}\beta + \eta_i + \varepsilon_{it} \quad (30)$$

where π_{it} is the inflation measure in country i in time t, x_{it} is a set of explanatory variables specific to country i in time t and $\eta_i + \varepsilon_{it}$ is the residual. We are interested in estimating the βs. While the error component ε_{it} has the usual properties (mean zero, uncorrelated with itself, uncorrelated with the vector x), the characteristics of the error component η_i define the estimation strategy we will adopt. In particular, given the extreme heterogeneity of inflation experiences we observe in our sample, and the extreme differences of the institutional features of the countries considered, we opt for treating the country specific error component, η_i, as a fixed effect rather than a random variable. This amounts to estimating the following equation,

$$\pi_{it} - \overline{\pi}_i = \alpha + (x_{it} - \overline{x}_i)\beta + \varepsilon_{it} - \overline{\varepsilon}_i \quad (31)$$

where $\overline{\pi}_i = \sum_t \pi_{it} / T$, $\overline{x}_i = \sum_t x_{it} / T$, $\overline{\varepsilon}_i = \sum_t \varepsilon_{it} / T$. In the actual estimation the dependent variable has been transformed to reduce heteroskedasticity of the error and thus improve the efficiency of the estimate. Also, since a few countries had three-digit inflation rates in some years, using the untransformed inflation rate as a dependent variable would give undue weight to these outlying observations. Instead, we use $D = \frac{\pi}{1+\pi}$ as the dependent variable, as in Cukierman et al., (1992, 1995). The variable D takes a value from zero to one.

5.4 The empirical results.

We begin by reproducing some of the results from the previous literature using our data set. In this way the actual impact of human capital inequality on inflation will be better evaluated. When the dependent variable D is regressed on openness only, using a FE estimator or simply

OLS on the pooled cross-section observations, the openness coefficient is negative and highly statistically significant, a results often highlighted in the empirical literature (Romer, 1993; Lane, 1995). The FE coefficient and standard error of openness is reported below

$$D = -0.0007(openness) + 0.15$$
$$(0.0001) \qquad (32)$$

The negative correlation between openness and inflation is robust to the inclusion of CBI among the explanatory variables, although it becomes statistically non-significant when variables representing the vulnerability of the central bank and high-level political change are included among the regressors.

The degree of independence of the central bank from political pressure CBI has often been found to have positive although a hardly statistically significant effect on inflation. Using our full sample we find a positive and statistically significant coefficient in the OLS and FE regressions. The CBI coefficients turn statistically non-significant and negative in the case of developed democracies for which the FE regression results are as follows

$$D = -0.07(CBI) + 0.09$$
$$(0.06) \qquad (33)$$

For this very restricted group of countries the OLS estimate of CBI is negative and highly statistically significant, a result that reproduces the one found by Cukierman et al., (1992).

5.5 Skill heterogeneity and inflation: empirical results.

Our new empirical results are illustrated in tables 3-5. The report fixed effect (top panel) and random effect (bottom panel) estimation results, for skilledp1, skilledp2 and skilledp3, respectively. The left hand side panel illustrates results where the dependent variable is D, while in the right hand side panel the dependent variable is the logarithmic transformation of the inflation rate π. The skilled ratio in all three tables is consistently positive and statistically significant at the 1-5 percent levels in all the most complete specifications. The sign of these estimates suggests that countries where agents are differently endowed with human capital tend to have higher inflation, once we keep constant those institutional factors that may impact upon the commitment to price stability. We explain this result in our model by showing that skill heterogeneity reduces the welfare costs of inflation, thus allowing the creation of a larger consent for high inflation. Tables 6 and 7 report results of robustness exercises. In particular, we test whether the found positive correlation between inflation and skill heterogeneity is robust to a segmentation of the full sample in Authoritarian and Non-authoritarian regimes. In Table 6 our first and most preferred measure of skill inequality, namely skilledp1, is consistently positively signed and statistically significant in both samples. Table 7 shows that even changing the definition of skill heterogeneity does not alter the central finding of these tables, which appears robust to a various specifications. Tables 8-10 report FE and RE estimation results for samples of developed (LDC=0) and less developed countries (LDC=1). Again, no matter what is the definition of skill adopted, skill heterogeneity appears to be significantly and positively correlated to inflation, although such a correlation is much higher for less developed countries.

Note that these results are robust to *(i)* changes in the dependent variable (as illustrated in tables 3-5, (ii) changes in the definition of skill used to generate measures of skill inequality. It is interesting to compare the results contained in tables 3-10 with those in table 11, which summarizes the findings when the education Gini coefficient is used as a measure of skill heterogeneity. Table 11 shows the impact of higher human capital inequality depends sharply on the groups of countries considered. For example we find the expected positive correlation between skill heterogeneity and inflation in a sample of developed economies (LDC=0), but we fail to find similar results in less developed countries. It is however important to keep in mind that the use of the education Gini coefficient as a measure of skill heterogeneity in this model is less appealing that the use of skilled-unskilled labour force shares, as discussed in section five, for the simple reason that in the model the education Gini coefficient would be a constant 0.5.

6. Concluding Remarks

The objective of this paper was to examine the link between skill heterogeneity and inflation. This issue was addressed within a dynamic general equilibrium framework that incorporated ex-ante, endogenous skill heterogeneity among workers. Numerical experiments based on a plausible parameterization of this model indicate that welfare costs of inflation relative to an optimal monetary policy are likely to decrease as skill heterogeneity increases. An implication of this feature is that a greater degree of skill heterogeneity would be associated with a greater tolerance for inflation, consequently implying a positive correlation between agent heterogeneity and inflation. An empirical study based on a panel of several countries finds evidence in support of this hypothesis.

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Appendix I

The first order conditions and equilibrium conditions for a non-stochastic steady state of this economy imply:

$$\frac{1}{C} = \lambda_1 + \lambda_2 \qquad (I.1)$$

$$\psi a = (1-\theta)\lambda_1 K^{\theta}\left\{\omega(H)N_1^{1-\nu} + N_2^{1-\nu}\right\}^{\frac{\nu-\theta}{1-\nu}}\omega(H)N_1^{-\nu} \qquad (I.2)$$

$$(1-\psi)\, a = (1-\theta)\lambda_1 K^{\theta}\left\{\omega(H)N_1^{1-\nu} + N_2^{1-\nu}\right\}^{\frac{\nu-\theta}{1-\nu}} N_2^{-\nu} \qquad (I.3)$$

$$\lambda_1 = \frac{\beta(\lambda_1 + \lambda_2)}{g} \qquad (I.4)$$

$$\theta\left(\frac{K}{N}\right)^{\theta-1} = \frac{1}{\beta} - 1 + \delta_k \qquad (I.5)$$

$$\frac{1-\theta}{1-\nu} K^{\theta} N^{\nu-\theta}\omega'(H)N_1^{1-\nu} = \frac{1}{\beta} - 1 + \delta_h \qquad (I.6)$$

$$C + \delta_k K + \delta_h H = K^{\theta} N^{1-\theta} \qquad (I.7)$$

Here λ_1 and λ_2 are the Lagrangian multipliers associated with the household budget and cash-in-advance constraints respectively. From equation (I.5), which is the equilibrium version of the first order condition for capital, it is clear that the capital to "aggregate labor" ratio is independent of inflation, and is given by:

$$\kappa = \frac{K}{N} = \left[\frac{1}{\theta}\left\{\frac{1}{\beta} - 1 + \delta\right\}\right]^{\frac{1}{\theta-1}}.$$

Of course, this is not the case for other variables as expressed by (, as a glance at the optimality conditions suggests.

Appendix II.

A. Proof of Proposition 1.

It is easy to check that the numerator of the expression for $\frac{dH}{dg}$ is positive. The sign of $\frac{dH}{dg}$ therefore depends on the sign of the denominator, which has been assumed to be negative by assumption (b) of the proposition. Therefore, $\frac{dH}{dg}$ is negative by construction. To see that $\frac{dC}{dg} < 0$, we take the total derivative of equation (30) and obtain

$$\frac{dC}{dg} = -\frac{(1-\theta)\beta\kappa^{\theta}\left(\phi(H)\right)^{\nu}\omega(H)}{\psi a g^{2}} + \left[\frac{(1-\theta)\beta\kappa^{\theta}\{\nu\left(\phi(H)\right)^{\nu-1}\phi'(H)\omega(H) + \left(\phi(H)\right)^{\nu}\omega'(H)}{\psi a g}\right]\frac{dH}{dg}.$$ The first term is obviously negative. Since $\frac{dH}{dg}$ is negative, and the term inside the brackets is positive under our assumptions, part (ii) of the proposition follows.

B. Proof of Proposition 2.

From condition (31) we can derive:

$$\frac{dN_1}{dg} = -\frac{\frac{1}{\beta} - 1 + \delta_h}{\frac{1-\theta}{1-\nu}\kappa^{\theta}}\left[\frac{\nu(\phi(H))^{\nu-1}\phi'(H)\omega'(H) + \omega''(H)(\phi(H))^{\nu}}{(\omega'(H)(\phi(H))^{\nu})^2}\right]\frac{dH}{dg}.$$

Again, since $\frac{dH}{dg}$ is negative by construction, given the conditions of Proposition 1 hold, the sign depends on the term in brackets. We can then check that $\frac{dN_1}{dg} < 0$ *iff* $-\frac{\omega''(H)}{\omega'(H)} > \nu\frac{\phi'(H)}{\phi(H)}$. Multiplying both sides by *H*, this amounts to $\Omega_{\omega'} > \nu\Omega_{\phi}$.

Also, $$\frac{dN_2}{dg} = -\frac{1}{\nu}\left(\frac{\psi}{(1-\psi)\omega(H)}\right)^{\frac{1}{\nu}-1}\left(\frac{\psi\omega'(H)}{(1-\psi)(\omega(H))^2}\right)N_1\frac{dH}{dg} + \left(\frac{\psi}{(1-\psi)\omega(H)}\right)^{\frac{1}{\nu}}\frac{dN_1}{dg}.$$

The first term on the right hand side is positive since $\frac{dH}{dg}$ is negative. The second term is negatve if $\frac{dN_1}{dg} < 0$, i.e. if $\Omega_{\omega'} > \nu\Omega_{\phi}$. Overall the sign of $\frac{dN_2}{dg}$ is ambiguous. Also note that

$$\frac{dN}{dg} = \phi'(H)N_1\frac{dH}{dg} + \phi(H)\frac{dN_1}{dg},$$

and,

$$\frac{dK}{dg} = \kappa^{\theta}\frac{dN}{dg}.$$

It is easy to check that parts (iii) and (iv) of the propositions follow from the given assumptions.

Appendix III

To perform numerical experiments on the impact of deep parameters for agents' heterogeneity we provide value to the remaining parameters, viz $\beta, \theta, \delta_k, \delta_h$, and g. These values are taken directly from relevant papers in the equilibrium business cycle literature, such as Hansen (1985) and Cooley and Hansen (1989), Lahiri (2002), and Canton(2002). The range of values for the parameter ν includes the value 0.4 chosen in the Prasad (1996). The values for α are chosen such that the productivity differential is around "2 or higher" as suggested in Kydland (1995). The parameter a is chosen to ensure an interior solution for work effort in all our numerical simulations – setting $a = 6.5$ ensures that this is the case. The parameter ψ, even though it can be interpreted as a parameter representing heterogeneity, is however fixed at 0.59, the value chosen in Prasad (1996). The reason for doing so will be discussed below, with reference to the measure of welfare cost considered in this paper. The other fixed parameters are given by the following: $\beta = .99$; $\theta = .36$; $\delta_k = .025$; $\delta_h = .00375$.

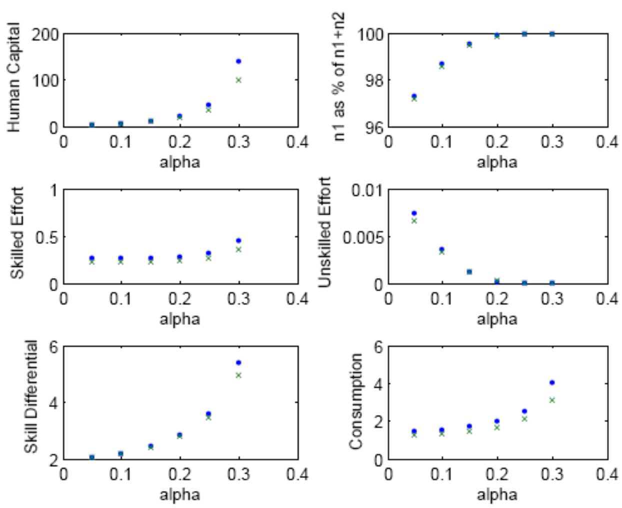

Figure 3(a): Steady state values of variables as α increases

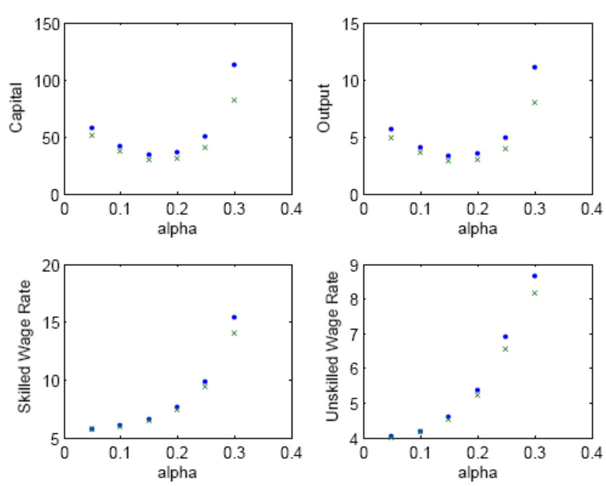

Figure 3(b): Steady state values of variables as α increases

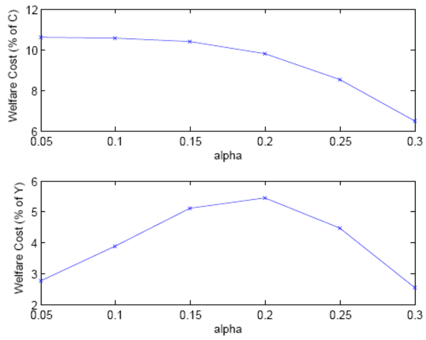

Figure 3(c): Welfare costs of inflation as α increases.

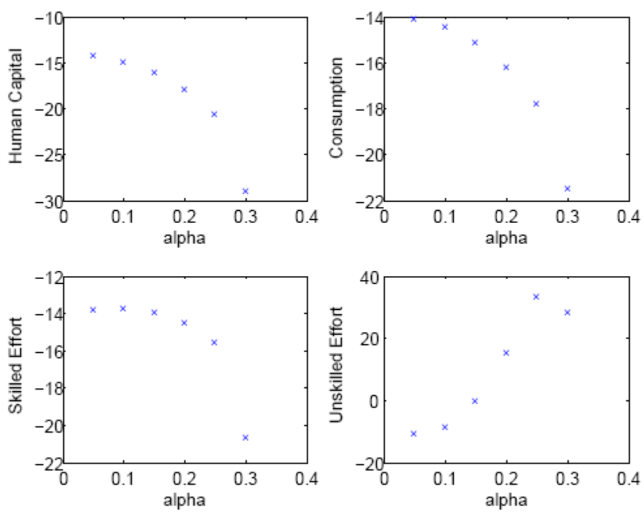

Figure 4(a): Percentage change relative to optimal policy as α varies.

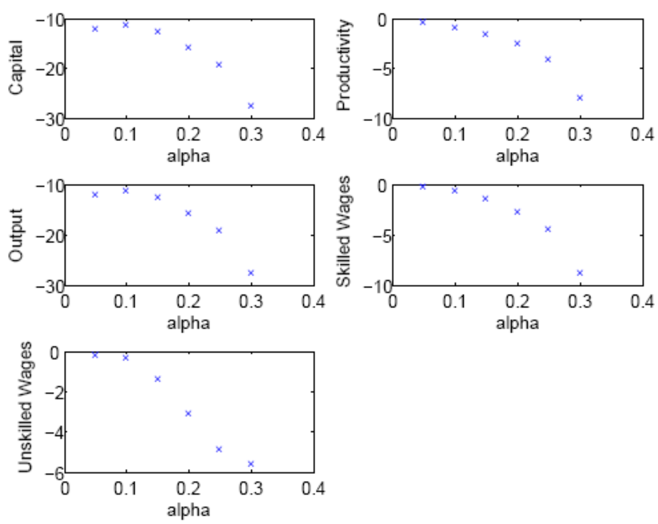

Figure 4(b): Percentage change relative to optimal policy as α varies.

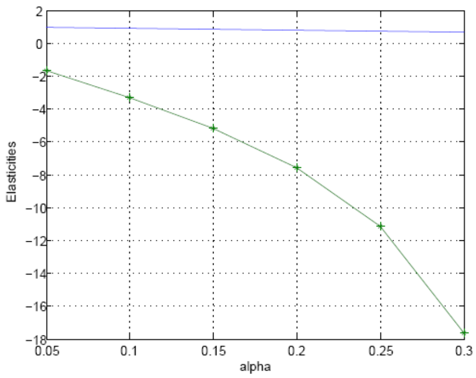

Figure 4(c): Elasticities $\Omega_{\omega'}$ and $\nu\Omega_{\phi}$ as α varies.

C. Numerical Procedure

The numerical procedure used to solve for the steady state of the model involves the construction of a "grid" of values for human capital, and searching this grid for a value that satisfies equation (28). Once this is found, equations (23)-(27) can be used to find the steady state values of other variables. Results are accurate up to three decimal places.

Appendix IV

We now turn to the discussion of experiments that vary α. First we interpret the changes in the steady state variables in Figures 3(a) and (b) as α is increased from 0.05 to 0.3. Higher α represents a higher marginal return to human capital, and therefore a greater steady state level of human capital. As a result, the skill differential increases, as does the productivity of skilled and unskilled effort leading to increases in wage rates. However, given that the productivity of skilled effort increases very dramatically relative to unskilled effort the latter decreases as α increases. Physical capital has a somewhat U-shaped response to changes in α – the initial increases in human capital and skilled effort make it more productive, but the decrease in unskilled labor counteracts this effect when α is relatively low. The same feature is reflected in the relationship between α and output, and consequently α and consumption.

It is interesting to note that the implications of changing α for some of the "dimensions of heterogeneity" discussed above differs from the implications of changing ν. First, the skill-differential, captured by the variable $\omega(H)$, increases very dramatically as α increases – for higher values of α in the range considered, skilled effort is almost six times as productive as unskilled effort. In the case in which ν varies, this variable increases but stays very close to the calibrated values for the skill differential suggested in the business cycle literature, e.g. Prasad (1996) and Kydland (1992), and this is one of the reasons we believe that the experiments varying ν are more relevant in informing the empirical investigation of section 5 in this paper. Secondly, the implication for the dimension captured by $N_1/(N_1+N_2)$ is very different. As α increases, the skill composition of the workforce shifts such that it constitutes mainly of skilled labor, which implies that the workforce is *less heterogeneous* for higher values of α. This makes it very difficult to interpret the experiments that involve α as reflecting increases in heterogeneity. Therefore, in what follows, we present a very brief discussion of this experiment.

Looking at the welfare cost estimates in Figure 3(c), we find that welfare costs of inflation relative to consumption decrease as α increases, while welfare costs relative to output initially increase and then decrease. Note that the magnitude of changes in this case is very small. To interpret these changes, we examine Figures 4(a) and 4(b). The size of the difference relative to the optimal policy, shown in Figures 4(a) and (b), seems to increase monotonically for most variables, except for unskilled work effort. From Figure 4(c), we see that $\Omega_{\omega'} > \nu\Omega_{\phi}$ holds for the entire range of values of α considered in the, while $\phi'(H) > 0$ does not hold. The former condition can be interpreted as before, so that, overall, inflation tax distortions increase as α increases. The discussion regarding welfare costs in the case of the experiments varying ν can be applied, with some modification, in this case as well. Here the behavior of unskilled effort would serve to exert an upward pressure on the welfare cost measure, so that decline in welfare costs as α increases would not be as striking as in the case with ν.

Table 1: Steady state values as g increases.

	$g = \beta$ (Optimal F	g	g	g
Human capital	3.2530	3.	3.	2.
Consumption	1.5146	1.	1.	1.
Skilled effort N_1	.2713	.2	.2	.2
Unskilled effort N_2	.0075	.0	.0	.0
$\frac{N_1}{N_1 + N_2} \times 100$	97.32	97	9	9
$\frac{N_2}{N_1 + N_2} \times 100$	2.68	2.	2.	2.
Capital stock	58.1946	56	5	5
Output	5.6741	5.	5.	4.
Skill differential	2.0608	2.	2.	2.
Skilled wages	5.8086	5.	5.	5.
Unskilled wages	4.0365	4.	4.	4.
Utility	.2521	.2	.2	.1
Welfare cost	0	.0	.0	.1
Welfare cost as % of consur	0	2.	3.	1
Welfare cost as % of output	0	0.	0.	2.

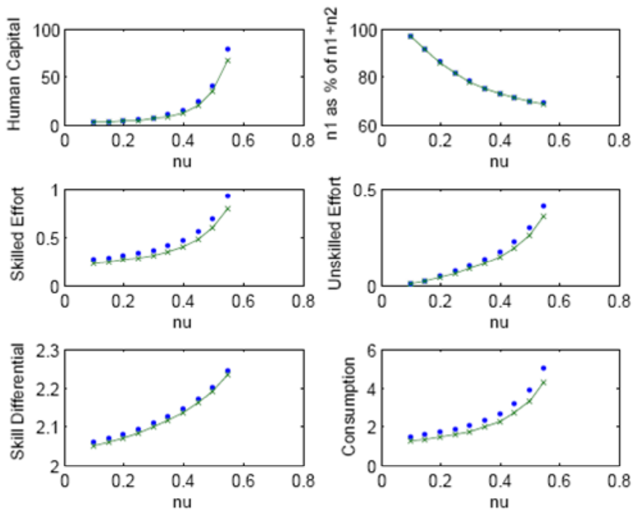

Figure 1(a): Steady State Values of Variables as ν increases

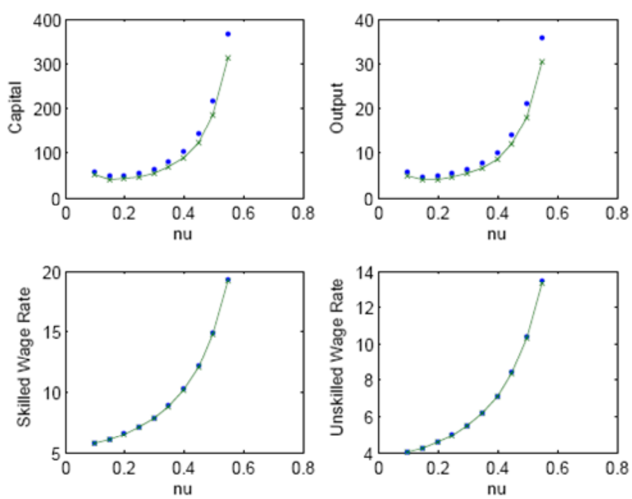

Figure 1(b): Steady state values of variables as ν increases

Optimal Policy ($g = \beta$	Policy with $g = 1.15$

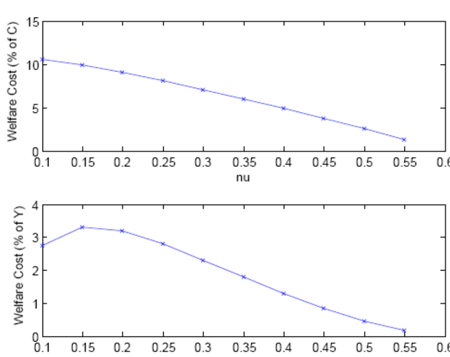

Figure 1(c): Welfare costs of inflation as ν increases

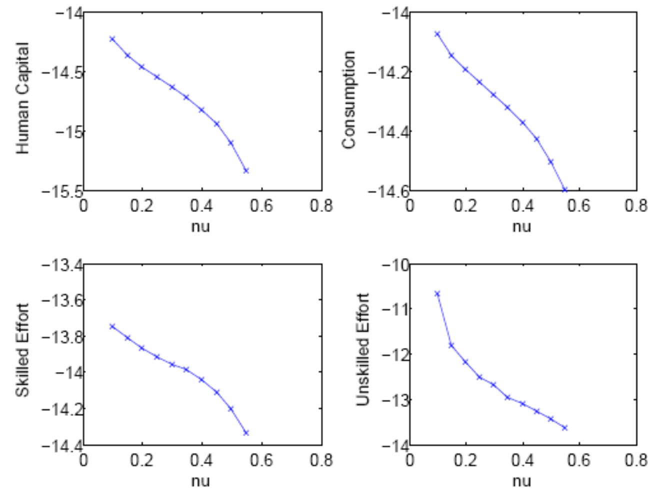

Figure 2(a): Percentage difference relative to the optimal policy as ν varies.

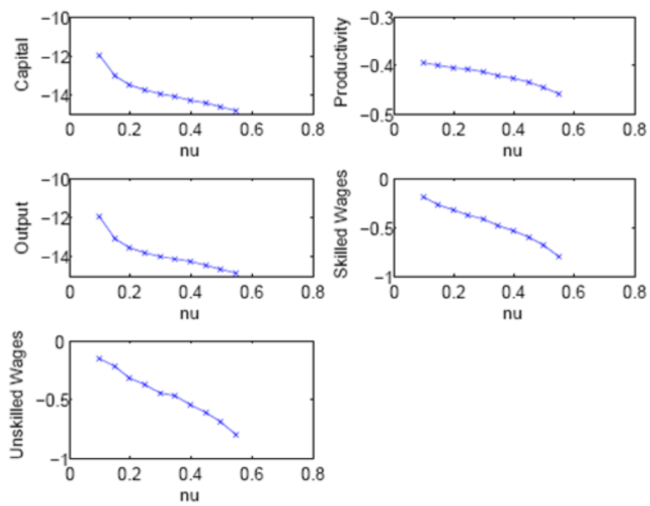

Figure 2(b): Percentage difference relative to the optimal policy as ν varies.

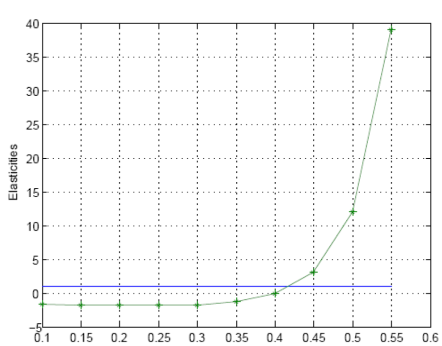

Figure 2(c): Elasticities $\Omega_{\omega'}$ and $\nu\Omega_{\phi}$ as ν varies.

Table 2. Summary statistics for the main variables					
Variable name	Obs.	Mean	Stand. Dev.	Min.	Max.
Inflation π	100	36.3	114.0	2.68	920.5
$D = \frac{\pi}{1+\pi}$	56	0.14	0.13	0.03	0.55
G25	105	0.48	0.24	0.13	0.94
G15	108	0.45	0.23	0.11	0.91
Openness	98	66.3	42.8	10.9	243.0
CBI	57	0.35	0.12	0.12	0.69
Vulnerability	56	0.29	0.31	0	1.28
High-level pol. ch	56	0.03	0.05	0	0.18
Skilledp1	96	0.25	0.19	0.01	0.79
Skilledp2	96	0.18	0.17	0.005	0.73
Skilledp3	96	0.07	0.08	0.0007	0.52

Table 3. Inflation and human capital inequality, 1960-2000. The dependent variable is $D = \frac{\pi}{1+\pi}$ in the left hand panel, and $\log \pi$ in the right hand panel, where π is the inflati rate.

Fixed Effect Estimation results.

Explan. variables	Inflation is D, FE 1960-2000			Inflation is $\log \pi$, FE 1960-2000		
Skilledp1	0.24***	0.29***	0.31***	1.00**	4.87***	4.70***
	(0.02)	(0.04)	(0.04)	(0.44)	(0.77)	(0.78)
Openness	----	----	-0.0006***	----	----	0.006
	----	----	(0.0002)	----	----	(0.004)
Central Bank Ind.	----	0.38***	0.36***	----	2.72	2.88
	----	(0.13)	(0.12)	----	(2.27)	(2.27)
Vulnerability (lag 0-6 months)	----	0.07***	0.07***	----	-0.07	-0.03
	----	(0.02)	(0.02)	----	(0.38)	(0.38)
High-level political	----	-0.05	-0.07	----	-2.63	-2.57
	----	(0.11)	(0.10)	----	(2.07)	(2.07)
Constant	0.04***	-0.12***	-0.09**	1.77***	-0.26	-0.56
	(0.009)	(0.04)	(0.04)	(0.13)	(0.79)	(0.81)

Random Effect Estimation results.

Explan. variables	Inflation is D, RE 1960-2000			Inflation is $\log \pi$, RE 1960-2000		
Skilledp1	0.20***	0.20***	0.21***	-0.27	1.69***	1.61***
	(0.02)	(0.04)	(0.04)	(0.30)	(0.58)	(0.58)
Openness	----	----	-0.0006***	----	----	0.001
	----	----	(0.0001)	----	----	(0.003)
Central Bank Ind.	----	0.18*	0.17*	----	0.53	0.53
	----	(0.10)	(0.09)	----	(1.16)	(1.14)
Vulnerability (lag 0-6 months)	----	0.11***	0.10***	----	0.89***	0.93***
	----	(0.02)	(0.02)	----	(0.31)	(0.31)
High-level political	----	0.03	0.02	----	-0.70	-0.67
	----	(0.11)	(0.10)	----	(1.83)	(1.83)
Constant	0.05***	-0.03	-0.0012	2.15***	1.26***	1.19**
	(0.01)	(0.03)	(0.03)	(0.11)	(0.45)	(0.47)
No. of observations	429	264	264	691	248	248
No. of groups	52	50	50	96	49	49

Table 4. Inflation and human capital inequality, 1960-2000. The dependent variable is $D = \frac{\pi}{1+\pi}$ in the left hand panel and $\log \pi$ in the right hand panel, where π is the inflati rate.

Fixed Effect Estimation results.

Explan. variables	Inflation is D, FE 1960-2000			Inflation is $\log \pi$, FE 1960-2000		
Skilledp2	0.22***	0.29***	0.32***	0.73	5.26***	5.09***
	(0.02)	(0.04)	(0.04)	(0.48)	(0.79)	(0.82
Openness	----	----	-0.0007***	----	----	0.003
	----	----	(0.0002)	----	----	(0.004)
Central Bank Ind.	----	0.41***	0.39***	----	3.14	3.24
	----	(0.13)	(0.12)	----	(2.24)	(2.25)
Vulnerability (lag 0-6 months)	----	0.08***	0.07***	----	-0.007	0.015
	----	(0.02)	(0.02)	----	(0.38)	(0.38)
High-level political	----	-0.06	-0.07	----	-2.64	-2.62
	----	(0.11)	(0.10)	----	(2.06)	(2.06)
Constant	0.06***	-0.10***	-0.07	1.91***	-0.06	-0.24
	(0.007)	(0.04)	(0.04)	(0.106)	(0.77)	(0.80)

Random Effect Estimation results.

Explan. variables	Inflation is D, RE 1960-2000			Inflation is $\log \pi$, RE 1960-2000		
Skilledp2	0.18***	0.20***	0.22***	-0.44	2.17***	2.05***
	(0.02)	(0.04)	(0.04)	(0.33)	(0.63)	(0.63)
Openness	----	----	-0.0006***	----	----	0.001
	----	----	(0.0001)	----	----	(0.003)
Central Bank Ind.	----	0.18*	0.17*	----	0.33	0.32
	----	(0.10)	(0.09)	----	(1.16)	(1.14)
Vulnerability (lag 0-6 months)	----	0.11***	0.10***	----	0.90***	0.94***
	----	(0.02)	(0.02)	----	(0.31)	(0.309)
High-level political	----	0.03	0.02		-0.60	-0.54
	----	(0.11)	(0.10)	----	(1.82)	(1.81)
Constant	0.08***	-0.01	0.01	2.16***	1.38***	1.32***
	(0.01)	(0.03)	(0.03)	(1.10)	(0.43)	(0.45)
No. of observations	429	264	264	691	248	248
No. of groups	52	50	50	96	49	49
F test						

Table 5. Inflation and human capital inequality, 1960-2000. The dependent variable is $D = \frac{\pi}{1+\pi}$ in the left hand panel and $\log \pi$ in the right hand panel, where π is the inflat rate.

Fixed Effect Estimation results.

Explan. variables	Inflation is D, FE 1960-2000			Inflation is $\log \pi$, FE 1960-2000		
Skilledp3	0.27***	0.37***	0.41***	0.25	6.36***	6.04***
	(0.04)	(0.07)	(0.07)	(0.75)	(1.25)	(1.27)
Openness	----	----	-0.0006***	----	----	0.006
	----	----	(0.0002)	----	----	(0.004)
Central Bank Ind.	----	0.44***	0.43***	----	3.76	3.89*
	----	(0.13)	(0.13)	----	(2.33)	(2.32)
Vulnerability (lag 0-6 months)	----	0.09***	0.08***	----	0.15	0.18
	----	(0.02)	(0.02)	----	(0.39)	(0.39)
High-level political	----	-0.10	-0.12		-3.59*	-3.50
	----	(0.11)	(0.11)	----	(2.13)	(2.12)
Constant	0.09***	-0.08*	-0.04	2.04***	0.40	0.09
	(0.005)	(.04)	(0.04)	(0.07)	(0.79)	(0.82)

Random Effect Estimation results.

Explan. variables	Inflation is D, RE 1960-2000			Inflation is $\log \pi$, RE 1960-2000		
Skilledp3	0.23***	0.31***	0.33***	-0.73	3.77***	3.65***
	(0.04)	(0.07)	(0.07)	(0.60)	(1.09)	(1.08)
Openness	----	----	-0.0006***	----	----	0.001
	----	----	(0.0001)	----	----	(0.003)
Central Bank Ind.	----	0.21**	0.20**	----	0.63	0.60
	----	(0.10)	(0.09)	----	(1.13)	(1.10)
Vulnerability (lag 0-6 months)	----	0.11***	0.11***	----	0.91***	0.94***
	----	(0.02)	(0.02)	----	(0.30)	(0.30)
High-level political	----	-0.005	-0.01		-1.15	-1.06
	----	(0.11)	(0.10)	----	(1.78)	(1.77)
Constant	0.10***	-0.002	0.03	2.12	1.48***	1.41***
	(0.17)	(0.03)	(0.03)	(0.09)	(0.42)	(0.44)
No. of observations	429	264	264	691	248	248
No. of groups	52	50	50	96	49	49
F test						

Table 6. Inflation and human capital inequality. Democratic and non-democratic regimes, 1960-2000. The dependent variable is $D = \frac{\pi}{1+\pi}$ where π is the inflation rate.

Fixed Effects Estimation results.

Exp. Var.	**FE Non-Authoritarian**			**FE Authoritarian**		
Skilledp1	0.24***	0.29***	0.30***	0.25***	In these regressions, c constant were dropped	
	(0.02)	(0.04)	(0.04)	(0.07)		
Openness	----	----	-0.0006***	----		
	----	----	(0.0002)	----		
Central Bank Ind.	----	0.39***	0.37***	----		
	----	(0.13)	(0.12)	----		
Vulnerability (0-6 months)	----	0.05**	0.05**	----		
	----	(0.02)	(0.02)	----		
High-level political change	----	-0.04	-0.06	----		
	----	(0.11)	(0.10)	----		
Constant	0.03***	-0.13***	-0.09**	0.11***		
	(0.01)	(0.04)	(0.4)	(0.01)		

Random Effects Estimation results.

Exp. Var.	**RE Non-Authoritarian**			**RE Authoritarian**		
Skilledp1	0.20***	0.20***	0.20***	0.19**	In these regressions, c and constant were dro	
	(0.02)	(0.04)	(0.04)	(0.08)		
Openness	----	----	-0.0005***	----		
	----	----	(0.0001)	----		
Central Bank Ind.	----	0.12	0.12	----		
	----	(0.09)	(0.09)	----		
Vulnerability (0-6 months)	----	0.10***	0.09***	----		
	----	(0.02)	(0.02)	----		
High-level political	----	0.10	0.09	----		
	----	(0.11)	(0.11)	----		
Constant	0.04**	-0.02	0.003	0.14***		
	(0.01)	(0.03)	(0.03)	(0.04)		
No. of observations	378	234	234	51		
No. of groups	44	42	42	8		

Table 7. Inflation and human capital inequality. Democratic and non-democratic regimes, 1960-2000. The dependent variable is $D = \frac{\pi}{1+\pi}$ where π is the inflation

Fixed Effects Estimation results.

Exp. Var.	FE Non-Authoritarian			FE Authoritarian	
Skilledp2	0.22***	0.28***	0.31***	0.27***	In these regressions, cbi constant were dropped.
	(0.02)	(0.04)	(0.04)	(0.8)	

Random Effects Estimation results.

Exp. Var.	RE Non-Authoritarian			RE Authoritarian	
Skilledp2	0.18***	0.19***	0.21***	0.23**	In these regressions, cbi constant were dropped.
	(0.02)	(0.04)	(0.04)	(0.09)	

Fixed Effects Estimation results.

Exp. Var.	FE Non-Authoritarian			FE Authoritarian	
Skilledp3	0.26***	0.36***	0.40***	0.60***	In these regressions, cbi constant were dropped.
	(0.04)	(0.07)	(0.07)	(0.21)	

Random Effects Estimation results.

Exp. Var.	RE Non-Authoritarian			RE Authoritarian	
Skilledp3	0.23***	0.30***	0.32***	0.52**	In these regressions, cbi constant were dropped.
	(0.04)	(0.07)	(0.07)	(0.22)	

Table 8. Inflation and human capital inequality. Developed and less developed countries, LDC = 0 and LDC = 1, respectively, 1960-2000. The dependent varia

$D = \frac{\pi}{1+\pi}$ where π is the inflation rate.

Fixed Effects (FE) Estimation results.						
Exp. Var.	FE, LDC = 1			FE, LDC = 0		
Skilledp1	0.40***	0.60***	0.57***	0.10***	0.15***	0.13***

Random Effects (RE) Estimation results.						
Exp. Var.	RE, LDC = 1			RE, LDC = 0		
Skilledp1	0.37***	0.52***	0.48***	0.09***	0.12***	0.09***
	(0.07)	(0.08)	(0.08)	(0.01)	(0.02)	(0.02)

Table 9. Inflation and human capital inequality. Developed and less developed countries, LDC = 0 and LDC = 1, respectively, 1960-2000. The dependent variab

$D = \frac{\pi}{1+\pi}$ where π is the inflation rate.

Fixed Effects (FE) Estimation results.						
Exp. Var.	**FE, LDC = 1**			**FE, LDC = 0**		
Skilledp2	0.44***	0.78***	0.78***	0.10***	0.15***	0.13***
	(0.05)	(0.11)	(0.11)	(0.01)	(0.02)	(0.03)

Random Effects (RE) Estimation results.						
Exp. Var.	**RE, LDC = 1**			**RE, LDC = 0**		
Skilledp2	0.41***	0.70***	0.69***	0.09***	0.12***	0.09***
	(0.05)	(0.10)	(0.10)	(0.01)	(0.02)	(0.02)

Table 10. Inflation and human capital inequality. Developed and less developed countries, LDC = 0 and LDC = 1, respectively, 1960-2000. The dependent variable

$D = \frac{\pi}{1+\pi}$ where π is the inflation rate.

Fixed Effects (FE) Estimation results.						
Exp. Var.	**FE, LDC = 1**			**FE, LDC = 0**		
Skilledp3	0.78***	1.81***	1.84***	0.11***	0.17***	0.11***
	(0.10)	(0.23)	(0.22)	(0.018)	(0.03)	(0.03)

Random Effects (RE) Estimation results.						
Exp. Var.	**RE, LDC = 1**			**RE, LDC = 0**		
Skilledp3	0.75***	1.69***	1.71***	0.10***	0.14***	0.11***
	(0.10)	(0.22)	(0.21)	(0.01)	(0.03)	(0.03)

Table 11. Inflation and human capital inequality, 1960-2000. The dependent vari is $D = \frac{\pi}{1+\pi}$ in the left hand panel and $\log \pi$ in the right hand panel, where π is th inflation rate.

Fixed Effect Estimation results.						
Explan. variables	Inflation is D, FE 1960-2000			Inflation is $\log \pi$, FE 1960-2000		
Gini (pop. 25+)	-0.35***	-0.47***	-0.45***	-1.95***	-4.61***	-6.12***
	(0.04)	(0.08)	(0.08)	(0.66)	(1.63)	(1.67)

Fixed Effects (FE) Estimation results.						
Exp. Var.	**FE, LDC = 1**			**FE, LDC = 0**		
Gini (pop. 25+)	-0.43***	-0.61***	-0.58***	0.22**	0.32***	0.22**
	(0.06)	(0.10)	(0.11)	(0.06)	(0.10)	(0.09)

Fixed Effects Estimation results.					
Exp. Var.	**FE Non-Authoritarian**			**FE Authoritarian (*a*)**	
Gini (pop. 25+)	-0.43***	-0.53***	-0.51***	-0.17**	In these regressions, cbi constant were dropped.
	(0.05)	(0.09)	(0.09)	(0.06)	