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Abstract

This paper describes a simple model of technology adoption which combines the two engines of growth emphasized in the recent growth literature: human capital accumulation and technological progress. Our model economy does not create new technologies, it simply adopts those that have been created elsewhere. The accumulation of human capital is closely tied to this adoption process: accumulating human capital simply means learning how to incorporate a new intermediate good into the production process. Since the adoption costs are proportional to the labor force, the model does not display the counterfactual scale effects that are standard in models with endogenous technical progress.

We show that our model is compatible with various standard results on the effects of economic policy on the rate of growth.

Key words: Technology adoption, growth, economic policy.
JEL classification: O40, E62, O1

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I. INTRODUCTION

The belief that economic policy is a major determinant of economic growth has been expressed in the writings of economists for over 300 years. Sir William Petty's (1676) comparative study of the standard of living in France and England and John Stuart Mill's (1848) discussion of the determinants of production increases are examples of early attempts to understand the growth process and to identify public policies that encourage economic development. The idea that government policy is important in shaping the growth process has been a recurrent theme of the development literature for the past three decades (see, for instance, Balassa et al (1982), Chenery et al (1986) and Krueger (1978)). Growth theorists have also shared this interest in the role of public policy; the neoclassical growth model of Solow (1956) has been used as testing ground to study the dynamic effects of numerous policies.

The empirical evidence based on the cross-country data that we have currently available is consistent with the idea that public policy can affect the course of economic development. Table 1 shows that, over the past 30 years, fast growing countries had less government consumption, lower inflation, lower black market exchange rate premia, and more trade than slow growing countries.

In this paper we discuss the effects of policy on economic growth making use of the theoretical insights provided by the recent growth literature. Instead of reviewing the various theoretical paradigms that have been recently proposed and their policy implications, we will organize most of our discussion around a simple model of technology adoption. This model, which is inspired by the work of Romer (1990) and of Rivera-Batiz and Romer (1991) encompasses two central themes of the recent growth literature: the importance of the process of human capital accumulation, and the role played by technological progress and by the introduction of new technologies.

Our basic model is presented in section II. In section III we discuss the effects of various types of government policies regarding taxes and government

spending, monetary policy, financial policies, trade and exchange rate policies. Section IV provides some conclusions.

TABLE 1

	Fastgrowers	Slowgrowers
Share of Investment in GDP	0.27	0.17
Secondary School Enrollment Rates	0.27	0.07
Primary School Enrollment Rates	0.90	0.52
Government Expenditures/GDP	0.14	0.13
Government Consumption/GDP	0.08	0.12
Inflation Rate	8.42	16.51
Standard Deviation of Inflation	8.75	19.38
Black Market Exchange Rate Premium	4.65	75.03
Standard Deviation of Black Market Premium	6.53	105.69
Share of Exports in GDP	0.44	0.29

Mean Per Capita Growth Rate = 1.92%; Fast Growers are countries whose per capita growth rate is greater or equal than the mean plus one standard deviation. The cutoff growth rate was 4% and the number of fast growers is 12. Slow growers are countries with per capita growth rates that are lower or equal to the mean minus one standard deviation. The cutoff growth rate for slow growers was -0.2% and the number of slow growers is 15. The variables included in the table is the subset of the policy variable included in the Levine-Renelt (1992) data set that are statistically different between the two groups of countries.

II. A SIMPLE MODEL OF TECHNOLOGY ADOPTION

Our economy is populated by N identical individuals who maximize their life-time utility defined as:

$$(1) \quad U = \int_0^{\infty} e^{-\rho t} \frac{1}{1-\sigma} [c_t^{1-\sigma} - 1] dt, \quad \sigma > 0, \rho > 0$$

where c_t represents the level of per capita consumption at time t (we will use

capital letters to denote aggregate quantities and lower case letters to denote per capita variables).

There is a single good in this economy which is produced by combining labor with a continuum of intermediate goods $X_t(i)$, with $i \in [0, A_t]$:

$$(2) \quad Y_t = B_1 N^\alpha \left[\int_0^{A_t} X_t^\gamma(i) di \right]^{(1-\alpha)/\gamma}$$

This production function is constant returns to scale if we maintain the range of intermediate inputs that are used in production (A_t) constant. Technological progress in this economy takes the form of endogenous increases in the range of intermediate inputs used in production. The parameter γ measures the extent to which the intermediate goods are substitutes: $1/(1-\gamma)$ is the elasticity of substitution between any two intermediate inputs. When $\gamma=1$ the intermediate goods are perfect substitutes.

The intermediate good $X_t(i)$ costs $p_t(i)$ units of output. This cost can be interpreted as the direct cost of producing the good, or as the price that needs to be paid to import it from abroad; $p_t(i)$ can also include any payments that need to be made to the foreign firm that holds the patent for $x(i)$.

Output Y_t can be used to purchase (or produce) intermediate goods, to consume or to invest in human capital (I_t):

$$(3) \quad Y_t = \int_0^{A_t} p_t(i) X_t(i) di + Nc_t + I_t$$

Our economy does not create new technologies, it simply adopts technologies that have already been discovered elsewhere. This adoption process is costly. In order to incorporate a new intermediate good into the production process it is necessary to invest resources. We assume that the cost of adopting new technologies

is proportional to the size of the work force, which in our model coincides with the population. This seems to be the most natural assumption: without it there would be scale effects associated with technology adoption implying that larger countries would find it easier to adopt new technologies.

In this model the accumulation of human capital is closely tied to the introduction of new goods into the production process: accumulating human capital simply means learning how to work with a new intermediate input. This notion of human capital accumulation is different from that implicit in Lucas (1988) and closer to the one described in Romer (1993a,b).

We assume that workers learn how to use new intermediate products sequentially, so that a worker who is capable of using intermediate good A can also work with goods in the interval $[0, A]$. A worker's human capital can then be measured by the most advanced intermediate good that he can use. Accumulation of human capital can thus be described as:

$$(4) \quad \dot{A}_t = B_2 (I_t/N)$$

Equation (4) implies that the production function for human capital is the same as that for output: to learn how to use a new good it is necessary to invest $1/B_2$ units of output. Postulating a different constant returns to scale production function for human capital would complicate the growth rate formula described below but would yield the same qualitative results.

Since new intermediate goods are created elsewhere, the economy is constrained by the fact that it cannot adopt technologies that have not been invented. That is, A_t has to be smaller than A_t^* which represents the 'technology frontier'. We will assume that our country is sufficiently far from the technology frontier that the restriction $A_t < A_t^*$ can be safely ignored.¹

II.1 The optimal use of intermediate goods

For a given A , the optimal level of utilization of intermediate goods can be determined by maximizing:

$$(6) \quad B_1 N^\alpha \left[\int_0^A X_t^\gamma(i) di \right]^{[(1-\alpha)/\gamma]} - \int_0^A p_t(i) X_t(i) di$$

The optimal level of $X_t(i)$ equates its price, $p_t(i)$, to its marginal product:

$$(7) \quad (1-\alpha) B_1 N^\alpha \left[\int_0^A X_t^\gamma(i) di \right]^{[(1-\alpha)/\gamma]-1} X_t^{\gamma-1}(i) = p_t(i)$$

This condition allows us to define output net of the intermediate goods cost as:

$$(8) \quad \text{Net Output} = \alpha B_1 N^\alpha \left[\int_0^A X_t^\gamma(i) di \right]^{[(1-\alpha)/\gamma]}$$

To determine the values of $X_t(i)$ it is necessary to make assumptions about the cost $p_t(i)$. We will assume that $p_t(i)$ is constant over time and identical for all i . The optimal level of $X_t(i)$, which in this case is the same for all $i \in [0, A]$, can be computed using equation (7).² Substituting the optimal level of X in the net output equation (8), we obtain:

$$(9) \quad \text{Net Output} = \alpha B_1^{1/\alpha} (1-\alpha)^{(1-\alpha)/\alpha} N A_t^\epsilon p^{-(1-\alpha)/\alpha}$$

where $\epsilon = (1-\gamma)(1-\alpha)/(\gamma\alpha)$.

Since we netted out the contribution of intermediate inputs, the expression depends only on labor and on the most advanced intermediate good which the representative worker can use.³

The elasticity parameter ϵ is a decreasing function of α : the introduction of new intermediate goods becomes more valuable when the labor share in production is low. The introduction of new goods also becomes more valuable as γ approaches zero. When γ is small there are sharply diminishing returns to each intermediate good so that introducing new intermediate goods in the production process becomes an important source of increases in production (when $\gamma \rightarrow 0$, $\epsilon \rightarrow \infty$). When the intermediate goods are perfect substitutes ($\gamma=1$) net output is independent of A_t ($\epsilon=0$). In this case there will be no accumulation of human capital, i.e. no resources will be devoted to training workers on how to incorporate new intermediate goods into the production process.

Depending how the value of ϵ compares to one we can have accelerating growth as in Romer (1986) ($\epsilon > 1$), declining growth ($\epsilon < 1$), or constant growth.⁴ In the remainder of the paper we will assume that $\epsilon=1$, so that net output is linear in A_t ; this is equivalent to assuming that $\gamma=1-\alpha$, which is the standard assumption implicitly used in Romer (1990) and in Grossman and Helpman (1990). This assumption is convenient because it allows us to focus on steady states and to describe the response of growth to policy with paper-and pencil methods. The same policy implications would be present in a model with no steady state but would have to be described using numerical methods. The fact that using the long time series collected by Maddison (1982) for various countries one cannot reject the hypothesis of no trend in the rate of growth lends some credence to the $\epsilon=1$ knife-edge hypothesis.

To simplify the notation we will denote net output per worker as:

$$(10) \quad \text{Net Output per Worker} = B A_t p^{-(1-\alpha)/\alpha},$$

where the new constant B is equal to $\alpha B_1^{1/\alpha} (1-\alpha)^{(1-\alpha)/\alpha}$. The resource constraint for this economy can thus be expressed in terms of per capita variables as:

$$(11) \quad B A_t p^{-(1-\alpha)/\alpha} = c_t + (I_t/N)$$

This economy grows always at a constant rate. This is a result of the preferences that we adopted and of three peculiar features of the economy's technology: (i) there is only one factor that can be accumulated (A_t); (ii) the production function is linear in this factor; and (iii) the technology used to increase the level of A_t coincides with the technology to produce output.

The rate of growth is given by the familiar expression:

$$(12) \quad g = [r - \rho]/\sigma$$

The real interest rate (r) is equal to:

$$(13) \quad r = B_2 B p^{-\alpha/(1-\alpha)}$$

Expression (13) can be easily interpreted: foregoing one unit of per capita output allows the economy to introduce a range B_2 of intermediate goods and introducing a new intermediate good into the production process increases net output by $B p^{-\alpha/(1-\alpha)}$.

Equations (13) and (14) imply that the rate of growth is:

$$(14) \quad g = [B_2 B p^{-\alpha/(1-\alpha)} - \rho]/\sigma$$

Now that we finished describing our economy it is useful to compare it with the 'Lab Equipment Model' of Rivera-Batiz and Romer (1991). The main difference between the two models has to do with the incorporation of new intermediate goods in the production process. Our economy does not invent new intermediate products, it simply adopts goods that were created elsewhere. To adopt these goods it is necessary to train workers to incorporate them in the production process, and so it

is natural to assume that the adoption cost is proportional to the number of workers. In Rivera-Batiz and Romer (1991) new intermediate goods are discovered and introduced at a fixed cost that is independent of the number of workers who will later adopt this production process. A firm which discovers a new good is granted a perpetual patent which allows it to charge a price for the intermediate good that is above its production cost. The decision to innovate results from comparing the cost of producing the innovation with the discounted stream of monopoly profits.

In the models of Romer (1990) and of Grossman and Helpman (1990) the steady state growth rate increases with the size of the economy. This scale effect reflects the fact that to introduce a new good it is necessary to incur a fixed cost that is independent of the size of the market. In contrast, the cost of adopting a new good in our economy is proportional to the population and hence there are no scale effects associated with the adoption process.

III. THE EFFECTS OF ECONOMIC POLICY

The model described in the previous section will now be used to review familiar policy implications and explore new ones.

III.1 Fiscal Policy

The effect of fiscal policy on economic growth has been extensively studied so only a brief review of the main results is warranted here.⁵

Looking at the growth formula (14) it is easy to see that a tax on income would lead to a decline in the rate of growth, since it would act like a reduction in B . Subsidies to the accumulation of human capital and to the adoption of new technologies have the same effect as increases in B_2 , so they foster growth.⁶

Given that the supply of labor is exogenous, a tax on consumption produces no distortions and hence it is equivalent to a lump sum tax. Imposing a constant tax on consumption leaves the growth rate unchanged. Surprisingly, this result also holds in some models with endogenous labor supply (see Stokey and Rebelo (1993)).

Our model abstracted from government expenditures. Its growth rate implications coincide, however, with those of a model in which publicly provided goods enter the production and/or the utility function in a separable manner.

If we introduced publicly provided goods into the production function (2) in a non-separable manner consistent with steady state growth we would obtain the same type results associated with the Barro (1990) model. The growth effect of an increase in public expenditures depends on the taxes used to finance those expenditures. Increases in the share of productive government expenditures in GDP increases the rate of growth when they are financed by consumption taxes. When distortionary taxes are used to fund public expenditure programs growth can decrease or increase in response to a boost in the share of government expenditures in GDP. The growth effect is the result of two conflicting forces: the distortionary effect of taxation and the increase in the productivity of the private sector associated with the government expenditures.

III.2 Monetary Policy

There has been a variety of authors who have explored the effects of monetary policy in the context of models of the Lucas (1988) - Uzawa (1965) type.⁷ The effects of monetary policy described by those authors, in settings in which money is introduced via a cash-in-advance constraint or by introducing money in the production function, could be easily translated into our framework. When money plays an important role in production or in facilitating investment, increases in the rate of inflation have the same effect as an increase in p or as a decrease in

B_2 in our model, leading to a decline in the rate of growth.

III.3 Trade Intervention and Exchange Rate Policy

Suppose for the moment that all intermediate goods are imported from abroad. Trade restrictions and tariffs will tend to raise the domestic price of these goods and reduce the rate of growth (see (14)). The evidence uncovered by De Long and Summers (1992) and by Jones (1992) suggests that the price of producer durables is lower in developed countries than in LDC's. Our model is consistent with this being an important factor in explaining the poor growth performance of LDC's.

Since the case in which all intermediate outputs are imported is an extreme one, it is useful to consider the case in which there are two groups of intermediate inputs with different prices. The price of goods with names in the interval $[0, aA]$ is p_1 , while goods with names in the interval $[aA, A]$ cost p_2 , where $0 < a < 1$. With a few algebraic manipulations it is possible to show that net output has, in this case, the form:

$$(15) \quad \text{Per Capita Net Output} = \alpha B A_1 [ap_1^{-(1-\alpha)/\alpha} + (1-a)p_2^{-(1-\alpha)/\alpha}]$$

The associated rate of growth is:

$$(16) \quad g = \{B_2 B [ap_1^{-(1-\alpha)/\alpha} + (1-a)p_2^{-(1-\alpha)/\alpha}] \cdot \rho\} / \sigma$$

Most trade and exchange rate policies distort the relative price of some goods. Trade barriers, quotas and tariffs make imported goods more expensive. Dual exchange rate systems or the emergence of black markets for foreign currency also distort relative prices. Equation (16) shows that, not surprisingly, if we maintain the price of the first group of intermediate goods, $p_1 = p$ and raise the price of the second type of goods through distortions the rate of growth will decline.⁸

Equation (16) does not, however, resolve the issue of whether it is possible to foster growth by taxing some intermediate goods and using the proceeds to subsidize other intermediate inputs. Easterly (1993) has shown in a different model that this is not possible and the same result applies here. In order for for this policy to work it must be possible to increase production by taxing some intermediate inputs and using the proceeds to subsidize other inputs. But this would work if the initial allocation of intermediate inputs were suboptimal, since the policy intervention under consideration simply rearranges the mix of intermediate inputs used in production.

III.4 Foreign Direct Investment

The effects of foreign direct investment on the rate of economic expansion can be given a simple interpretation in terms of equation (14). It is natural to assume that the cost of adopting new technologies is lower when it is carried out by firms which have experience in using those technologies. In terms of our growth formula this translates into a higher value for B_2 and a more rapid rate of growth.⁹ This mechanism could be made more precise if we introduced the type of learning-by-doing dynamics explored in Stokey (1988) and Young (1991) in the process of technology adoption.

III.5 Policy Uncertainty

Two of the variables in Table 1, the standard deviation of inflation and of the black market premium, suggest that uncertainty about policy is important. To explore this effect it is useful to employ a simpler model in which there are two types of capital: one that produces a low but riskless rate of return and another that generates returns that are high but risky. This model is simply a re-interpretation of Merton's (1969) model of portfolio selection under uncertainty so

our presentation will be brief.

Agents in this economy make production and consumption decisions so as to maximize the expected value of life-time utility described in equation (1). The production function is linear in the capital stock in both the risky and the riskless sector. To simplify we assume that capital does not depreciate over time. The law of motion for the capital stock is given by:

$$(17) \quad dK = \{[\phi_t R_2 + (1-\phi_t)R_1]K_t - C_t\}dt + \phi_t K_t v dz$$

In this expression ϕ_t represents the fraction of capital used in the risky sector. R_1 is the rate of return in the safe sector while R_2 is the expected rate of return in the risky sector. Naturally, we assume that $R_1 < R_2$, otherwise no capital would be used in the risky sector. The parameter v represents the volatility in the returns to the risky sector; dz is a Wiener process.

Merton (1969) showed that both the consumption-capital ratio and the fraction of capital employed in the risky activity are constant in this economy:

$$(18) \quad C_t/K_t = [\rho - (1-\sigma)R_1]/\sigma - (1-\sigma)(R_2-R_1)^2/(2v^2\sigma^2)$$

$$(19) \quad \phi = (R_2-R_1)/(v^2\sigma)$$

This implies that the stochastic process for the capital stock is:

$$dK = \left\{ (R_1-\rho)/\sigma + (1+\sigma)(R_2-R_1)^2/(2v^2\sigma^2) \right\} K_t dt + (R_2-R_1)/(v \sigma) K_t dz$$

The growth rate has thus a mean equal to $(R_1-\rho)/\sigma + (1+\sigma)(R_2-R_1)^2/(2v^2\sigma^2)$, and a variance rate equal to $(R_2-R_1)^2/(v \sigma)^2$. As one would expect, economies with higher risk aversion (σ) invest a higher fraction of the capital stock in the safe

technology, so that they reduce growth volatility at the cost of a lower mean rate of economic expansion.

This model suggest that an increase in the volatility (i.e. in v^2) of the return to the risky sector lowers the average rate of growth.¹⁰

It is worthwhile stressing that in order for the first of these results to hold it is essential that there exist a risk free activity. If $R_1=0$, so that investment could take place only in the risky sector the effects of uncertainty on the rate of growth depend on the degree of risk aversion, as is familiar from Levhari and Srinivasan's (1969) classic paper on savings under uncertainty and from Eaton's (1981) analysis of the interaction between taxation and uncertainty. In this case the law of motion of the capital stock is:

$$(20) \quad dK = [(R_2 - \rho)/\sigma - \frac{1}{2} (1 - \sigma)v^2] K dt + v K dz$$

For values of σ greater than one, the income effect on consumption of a given change in R_2 dominates the substitution effect so the rate of growth increases with increases in return volatility. The reverse takes place when $\sigma < 1$. When $\sigma = 1$ the mean instantaneous rate of growth is independent of the degree of uncertainty in production outcomes.

Even though we described the production uncertainty in the model as having a technological origin, it is easy enough to re-write the model so that the source of uncertainty stems from policy variables such as inflation, tax rates, or the likelihood of expropriation. Suppose there are two sectors in the economy, a formal sector in which it is difficult to evade taxation and an informal sector which does not pay taxes. In order for production to take place in both sectors it must be the case that the formal sector is more productive ($R_2 > R_1$). Higher uncertainty about taxes leads in this setting to lower rates of growth. The impact of this uncertainty is greater the higher the expected difference in the productivity of the two sectors ($R_2 - R_1$).

III.6 Financial Policy

This model can be used to illustrate some of the channels through which financial markets and financial policies can affect the rate of growth. For example, we just demonstrated that greater uncertainty lowers growth. Consequently, financial markets that allow individual to diversify and reduce uncertainty will promote faster growth. Moreover, policies that inhibit financial markets or institutions from optimally facilitating the ability of individuals to hold diversified portfolios will reduce growth (see Levine (1991) and Saint-Paul (1992)).

Our technology adoption model demonstrates another channel through which financial policy can affect growth. In the model, it is costly to adopt new and better technologies. To incorporate a new intermediate good into the production process however, resources must be invested. King and Levine (1993) modify a model similar to this one by (i) assuming that these resources for developing new intermediate goods must be financed externally; and (ii) assuming that the ultimate value of intermediate goods is costly to discern ex ante. Financial intermediaries arise to research the value of investing in new intermediate goods and selecting the most promising ones to finance. In this model policies that interfere with the ability of financial intermediaries to select the investment opportunities with the best chances of success will slow economic growth.

IV. CONCLUSION

In this paper we described a model economy in which technological progress takes the form of the introduction of new intermediate products into the production process. Our economy does not create new goods, it simply adopts goods that have been created elsewhere. This adoption process is costly because it involves training the work force to use these new technologies. Learning how to use new goods is the only type of human capital accumulation that takes place in the

economy. This contrasts with the human capital accumulation process described in Lucas (1988) model, which is independent of the introduction of new technologies

Since new technologies are created in only a handful of developed countries models of technology adoption such as the one outlined here are natural vehicles to think about cross-country differences in rates of growth.

We have shown that many of the positive (as opposed to normative) policy implications that had been derived in the context of the class of models proposed by Lucas (1988) and Uzawa (1965) continue to hold in our simple model of endogenous technology adoption. We think that further work on growth models with technology adoption will sharpen our understanding of the link between economic policy and the development process.

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¹When the economy's technological level, A_t is close to A_t^* the economy may start devoting resources to the discovery of new technologies, so we might observe the type of transition emphasized by Goodfriend and McDermott (1990).

² $X_t(i)$ is obviously equal to zero for $i \in [A, \infty]$.

³The notion of an intermediate good being more advanced is more natural in the quality ladder models of Aghion and Howitt (1992) and Grossman and Helpman (1991) than in this type of model in which intermediate goods are symmetric.

⁴In order for the growth rate to be well defined life-time utility (see equation (1)) must be finite; $\sigma > 1$ is a sufficient condition for finiteness of U in economies with positive growth.

⁵For general references to this literature see Barro and Sala-i-Martin (1993) and Easterly and Rebelo (1993).

⁶See Parente and Prescott (1991) for a discussion of the effects of taxation on technology adoption.

⁷See, for instance, Mino (1990) and Wang and Yip (1991).

⁸Barriers to trade are unambiguously bad for growth in this model because we ruled out infant industry phenomena.

⁹See Romer (1993a,b) for a discussion of the role of foreign direct investment in the growth process.

¹⁰Higher volatility in the returns to the risky sector result in lower volatility in the rate of growth. If we think of LDC's as having higher return volatility, this model has the counterfactual prediction that the variability of growth should be smaller in LDC's than in developed countries.