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Economic growth and the relative price of capital

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Abstract

This paper examines empirically the relationship between the relative price of capital and the rate of economic growth. In the results, machinery appears to be the most important component of capital: when the relative price of machinery and the relative price of nonmachinery are included in a Barro (1991) growth regression, a strong negative relationship between growth and the machinery price emerges while the nonmachinery price enters insignificantly. These results indicate that the tax treatment of machinery is an important policy instrument with respect to long-term growth and welfare.

Key words: Economic growth; Investment; Machinery investment; Price of capital

JEL classification: E60; O40

1. Introduction[1]

The notion that a tax on capital will have a negative effect on the growth rate of a closed economy comes as no surprise to modern economists. Under

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[1] After the first version of this paper was completed, I discovered that De Long and Summers (1991) were conducting parallel research. Their work focuses primarily on the relationship between growth and the quantity of investment whereas this paper emphasizes the effect of distortions in the relative price of investment on economic growth. The important differences between our two papers are discussed in a later section.

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plausible assumptions, such a tax raises the price of capital, resulting in a decline in new investment undertaken by firms. This decline in capital accumulation in turn reduces the growth rate of the economy in any standard growth framework, either in the long run or along a transition path to a new steady state. When open economy models are considered, this line of reasoning extends naturally to tariffs on capital imports.[2] Together, these arguments suggest that distortions in the price of capital are an important determinant of economic growth in both closed and open economy models. Yet while the theoretical relationship between growth and price distortions is fairly obvious, little empirical analysis has been conducted to estimate the magnitude of this effect. In the public finance literature, much has been written concerning investment tax credits and their effect on capital accumulation (e.g., Summers, 1981), but the linkage to growth has not been estimated since only a single country is usually considered. Also, a long tradition of work in development has focused on trade, tariffs, and growth; Edwards (1989) provides an excellent review of this literature, but concludes that no good measures of price distortions have been found and that the issues are far from settled.

This paper takes advantage of the disaggregated benchmark data used to construct the Summers and Heston (1988) Penn World Tables in order to analyze the effect of distortions in the price of capital on economic growth. Because of the nature of the data, it is more appropriate to speak of 'price structure' than to speak directly about taxes; however, the empirical results apply immediately to issues of government-imposed price distortions such as tariffs and taxes. The results indicate that a decrease in the tax applied to capital (or an increase in subsidy) can have a substantial positive effect on the growth rate of output. Furthermore, the component of capital that appears most crucial for economic growth is machinery, a subaggregate that includes capital ranging from tractors to computers.

The paper is organized as follows. Section 2 discusses the disaggregated data from the benchmark surveys underlying the Penn World Tables, which is used to construct the various capital price measures. Section 3 documents the empirical results. Section 4 interprets the results with a simple application to India, and Section 5 concludes.

[2]Again, certain exceptions are possible. For example, in models by Krugman (1987) tariffs can be 'optimal', at least in the space of second-best solutions. Consider the case of an infant industry in a developing country that exhibits increasing returns to scale over some range but cannot enter a market because of initially high average costs. Protection of such an industry in the short run could allow it to achieve the scale necessary to compete in the international market.

2. Data issues

2.1. Measuring the relative price of capital

The benchmark surveys from which the Summers and Heston (1988) Penn World Tables are derived provide an excellent opportunity for comparing prices because they incorporate differences in purchasing power parity across countries.[3] Although benchmark data is available for only a restricted sample of 65 countries, data quality is generally much higher for countries which participated in a benchmark survey. Thus, data from developing as well as developed countries can be used in the estimation with less concern for standard issues of measurement error. The reader is referred to Kravis, Heston, and Summers (1978, 1982) for a more detailed discussion concerning the benchmark data.

Benchmark estimates are also available at a more disaggregated level than is the Summers and Heston Penn World Tables data set, and this disaggregated data is used to construct measures of the relative price of capital and several of its components. Domestic capital formation (or total investment) is made up of two categories: construction and producer durables. From the construction category, we focus on the nonresidential subaggregate. From the producer durables category, relative price levels are constructed for all three major subaggregates: transportation equipment, electrical machinery, and nonelectrical machinery. Relative price levels are constructed by dividing the PPP-adjusted deflators of these variables by the PPP-adjusted price of consumption.[4,5]

From the disaggregated benchmark data for 1980, relative prices for 56 countries are obtained. Then, using preliminary benchmark data from 1985 and the benchmark data from 1975, another nine countries are added to the sample. The technique of Seemingly Unrelated Regression (SUR) was used to construct 1980 fitted values from either a 1975 or a 1985 benchmark. SUR makes use of the fact that the residuals of a regression of the 1980 price of durables on the 1975 price of durables will be correlated with the residuals of a regression of the 1980 price of construction on its 1975 value, etc. The 1980 fitted values for the nine additional countries were joined with the original 1980 data for the 56 countries to produce the 65-country sample.[6]

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[3]See Summers and Heston (1988) for a discussion of their methods and the advantages and disadvantages of their data.

[4]Consumption is used as a measure of the output good instead of GDP because the GDP price index includes investment prices. A switch to GDP has little effect on the results, however.

[5]It is incorrect to think of this price ratio as reflecting the incentive to invest versus consume: consumption taxes do not affect the rate of return to capital in most growth models and therefore do not affect growth rates.

[6]The results are not sensitive to the exclusion of the nine additional countries.

2.2. *Growth rates, initial GDP, and the relative price of machinery*

The empirical results presented below indicate that the components of investment that are most highly correlated with growth, at least insofar as relative prices are concerned, are the electric and nonelectric machinery categories. In other words, nonresidential and residential construction seem to be much less important for growth than the other primary component of investment, producer durables. And within producer durables, the two machinery components are distinctly correlated with growth in contrast to the transportation equipment category. Statistical evidence for these findings will be presented later. For the moment, we turn to a more careful examination of the relative price of the machinery component and its effect on growth.

Fig. 1 presents a simple scatterplot of the growth rate from 1960–1985 and the relative price of machinery for the 65-country sample using the standard World Bank country codes as plot symbols. The growth rate and the relative price of machinery appear to be negatively related, and indeed, the simple correlation coefficient for these two variables is -0.31 (s.e. $= 0.12$). Countries with higher relative prices of machinery in 1980 tend to have slower growth rates over the period. Apart from problems with using only a simple correlation (these problems will be dealt with in the regression analysis below), an obvious question about this result involves causality: does the correlation arise because a high relative price causes slower growth, or does slower growth result in a high

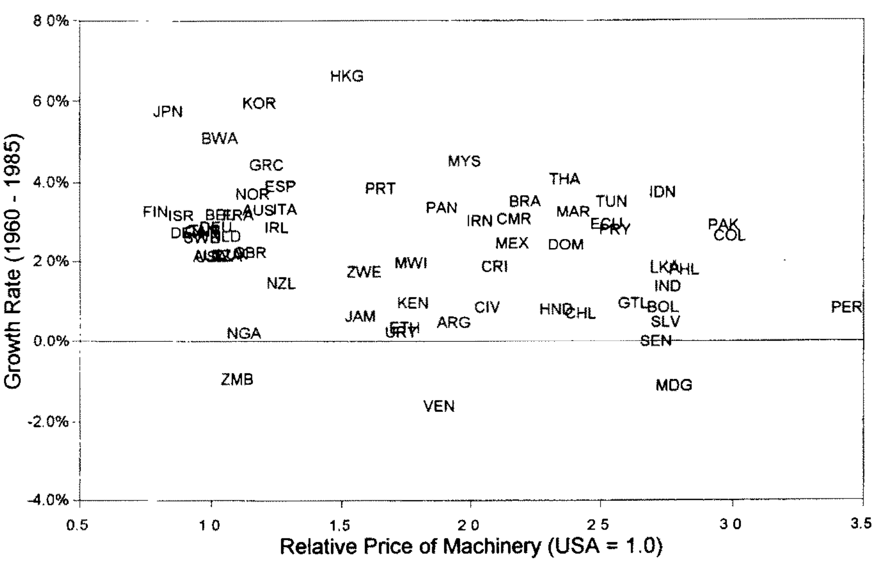

Fig. 1. Annual GDP growth vs. machinery price ($N = 65$).

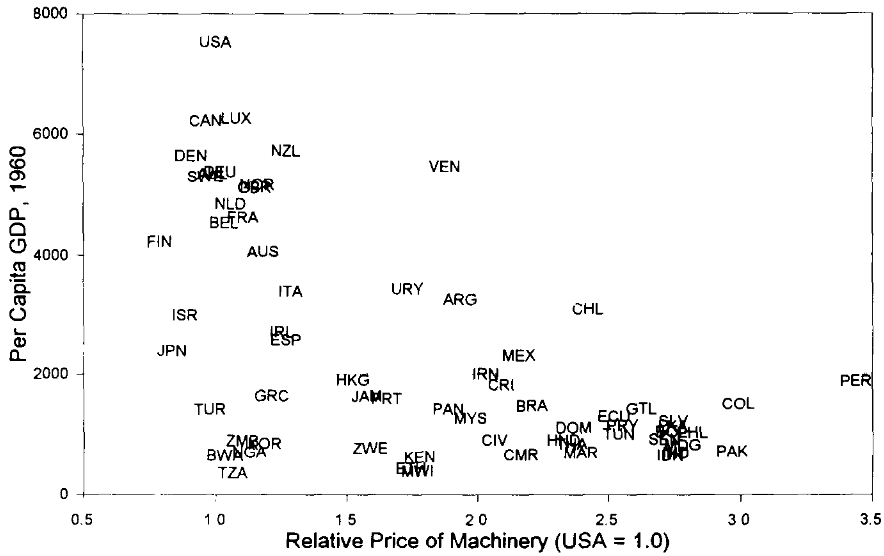

Fig. 2. Initial per capita GDP vs. machinery price ($N = 65$).

relative price by 1980? This is a question which we will postpone until after the empirical results are presented, but in the end it cannot be resolved completely.

Fig. 2 shows the relative price of machinery plotted against the initial (1960) level of GDP per capita in thousands of 1980 U.S. dollars. A strong negative relationship is readily apparent in this graph:[7] 1960 GDP and the relative price of machinery have a simple correlation of -0.58 (s.e. $= 0.10$). Thus, it is crucial to include 1960 GDP in any growth regression; otherwise the relative price of machinery could simply be capturing differences in the initial stage of development.

3. Results

In order to analyze economic growth, the methodology employed by Barro (1991) is followed. The growth rate from 1960 to 1985 for a cross-section of countries in the Summers and Heston data set is regressed on several variables that are, or at least are close to being, exogenous. Thus, variables such as the investment share or population growth are excluded from the regression, as

[7] Interestingly, this relationship is one of the predictions of some endogenous growth models with fixed factors, e.g., Rebelo (1991).

these variables are endogenous in many growth models. The Barro (1991) specification includes the starting level of GDP, two proxies for human capital, a government consumption variable, and several variables used to capture basic country characteristics that may plausibly have an effect on growth. Table 1 lists these variables together with summary statistics.

The first line of results in Table 2 corresponds to the Barro regression for the 65-country sample using the Barro–Wolf data set discussed in Barro (1991). The results found by Barro are broadly confirmed. Namely, holding proxies for human capital constant, the initial level of GDP has a significant negative coefficient, suggesting the qualified convergence result observed in previous studies. The enrollment ratios for secondary and primary schools that proxy for human capital have positive coefficients, although their standard errors are generally larger than those found by Barro. The ratio of government consumption (i.e., nondefense and noneducation spending) to GDP enters negatively and very significantly, and Barro argued that this results from the distorting effects of government taxation and government expenditure programs. Several country characteristic variables (see Table 1) were also included in the regression, but their coefficients are omitted from the table. The signs and significance levels of these variables are consistent with the findings of Barro.

In the remainder of this paper, we will focus primarily on specifications in which the relative price variables are added to the regression. Barro (1991) provides a detailed analysis of the other variables included in the growth regression.

3.1. Growth and the relative price of machinery

When the relative price of machinery is included in the basic Barro specification, it enters negatively and significantly, as shown in the second regression of Table 2.[8] According to the cross-sectional evidence of this regression, a unit increase in the relative price of machinery is associated with a reduction in the annual growth rate of a country of three-quarters of a percentage point. Fig. 3 illustrates this finding graphically. The figure plots the relative price of machinery against the portion of growth that is unexplained when all variables except the relative price of machinery are taken into account. Thus, a simple regression line when plotted in Fig. 3 would have the slope of -0.0076. The graph also shows that even though Peru is an outlier, the negative relationship between growth and the relative price of machinery is clear when this country is omitted.

An important issue in using the Summers and Heston data is that of measurement error. Data quality varies across countries, and not surprisingly this

[8]This equation represents the basic specification used throughout this paper. However, some equations are estimated without including the country characteristic variables because of collinearity. See the table notes for exact information.

Table 1
Variable statistics

Variable (N = 65 unless noted)	Mean	Std. dev.	Minimum	Maximum
Basic Barro (1991) variables				
Growth rate, 1960–85	0.024	0.016	− 0.016	0.066
Growth rate, 1960–75	0.031	0.017	− 0.007	0.071
Growth rate, 1970–85	0.018	0.020	− 0.041	0.063
GDP in 1960	2.228	1.895	0.208	7.380
GDP in 1970	3.152	2.627	0.283	9.459
Sec. school E.R., 1960	0.265	0.230	0.010	0.860
Sec. school E.R., 1970	0.396	0.274	0.020	1.000
Prim. school E.R., 1960	0.844	0.292	0.050	1.440
Prim. school E.R., 1970	0.920	0.245	0.170	1.290
Govt. cons. share, 1970–85	0.101	0.051	0.014	0.240
Country characteristic variables				
War indicator variable	0.385	0.490	0.000	1.000
Number of revolutions	0.138	0.189	0.000	0.850
Socialist govt. indicator	0.062	0.242	0.000	1.000
Latin America indicator	0.277	0.451	0.000	1.000
Sub-Saharan Africa indicator	0.200	0.403	0.000	1.000
Relative price variables				
Total investment	1.423	0.526	0.518	2.745
Nonres. construction (N = 60)	1.540	1.036	0.557	5.535
Producer durables	1.768	0.738	0.814	3.639
Transport equipment	1.863	1.078	0.668	6.245
Machinery	1.787	0.713	0.787	3.438
Electrical machinery	1.973	0.962	0.612	4.798
Nonelectrical machinery	1.760	0.689	0.754	3.440
Nonmachinery investment	1.349	0.564	0.428	3.147
Investment share in GDP variables				
Investment rate, 1960–85 avg.	0.199	0.073	0.055	0.369
Investment rate, 1970–85 avg.	0.204	0.072	0.052	0.383
Machinery inv. share, 1980	0.054	0.027	0.015	0.145
Other price distortion variables (N = 51)				
Tariff revenue share	0.152	0.140	0.001	0.480
Effective rate of protection	0.595	0.608	0.020	2.650
ERP indicator (0,1,2)	0.745	0.821	0.000	2.000

Table 2
Growth and the relative price of machinery – Dependent variable: annual growth rate of GDP per capita

Sample	Initial GDP per capita	Initial secondary school E.R.	Initial primary school E.R.	Avg. govt. consumption/GDP	Relative price of machinery	S.E.E.	R^2
1960–1985 period							
Total*	−0.0068	0.0191	0.0052	−0.0952			
($N = 65$)	(0.0011)	(0.0073)	(0.0050)	(0.0347)	—	0.0106	0.64
Total*	−0.0075	0.0088	0.0023	−0.0864	−0.0076		
($N = 65$)	(0.0010)	(0.0096)	(0.0045)	(0.0307)	(0.0036)	0.0100	0.68
GDP > 10% of U.S.	−0.0071	0.0308	0.0197	−0.1322	−0.0072		
($N = 50$)	(0.0015)	(0.0120)	(0.0071)	(0.0424)	(0.0035)	0.0112	0.53
GDP > 20% of U.S.	−0.0072	0.0123	−0.0034	−0.0725	−0.0195		
($N = 29$)	(0.0018)	(0.0115)	(0.0068)	(0.0435)	(0.0048)	0.0107	0.62

1960–1975 period							
Total*	− 0.0084	0.0094	− 0.0010	− 0.0973	− 0.0148		
(N = 65)	(0.0011)	(0.0103)	(0.0077)	(0.0318)	(0.0037)	0.0111	0.64
GDP > 10% of U.S.	− 0.0084	0.0264	0.0083	− 0.1557	− 0.0118		
(N = 50)	(0.0013)	(0.0108)	(0.0108)	(0.0410)	(0.0038)	0.0116	0.56
GDP > 20% of U.S.	− 0.0082	0.0092	− 0.0217	− 0.1086	− 0.0203		
(N = 29)	(0.0015)	(0.0127)	(0.0131)	(0.0344)	(0.0061)	0.0099	0.72
1970–1985 period							
Total*	− 0.0058	− 0.0016	0.0063	− 0.1037	− 0.0049		
(N = 65)	(0.0016)	(0.0158)	(0.0082)	(0.0399)	(0.0045)	0.0142	0.58
GDP > 10% of U.S.	− 0.0049	0.0392	0.0295	− 0.1474	− 0.0034		
(N = 50)	(0.0023)	(0.0170)	(0.0136)	(0.0501)	(0.0051)	0.0166	0.34
GDP > 20% of U.S.	− 0.0059	0.0338	0.0184	− 0.0826	− 0.0188		
(N = 29)	(0.0026)	(0.0199)	(0.0245)	(0.0600)	(0.0051)	0.0146	0.46

A constant term is suppressed in the results. Regressions labelled with an asterisk (*) have the following country characteristics variables taken from Barro 1991) suppressed as well: war indicator variable, number of revolutions during 1960–1985, socialist government indicator, and indicator variables for the Latin American and Sub-Saharan Africa regions. These variables are omitted from the other specifications. White heteroskedasticity-robust standard errors are reported in parentheses.

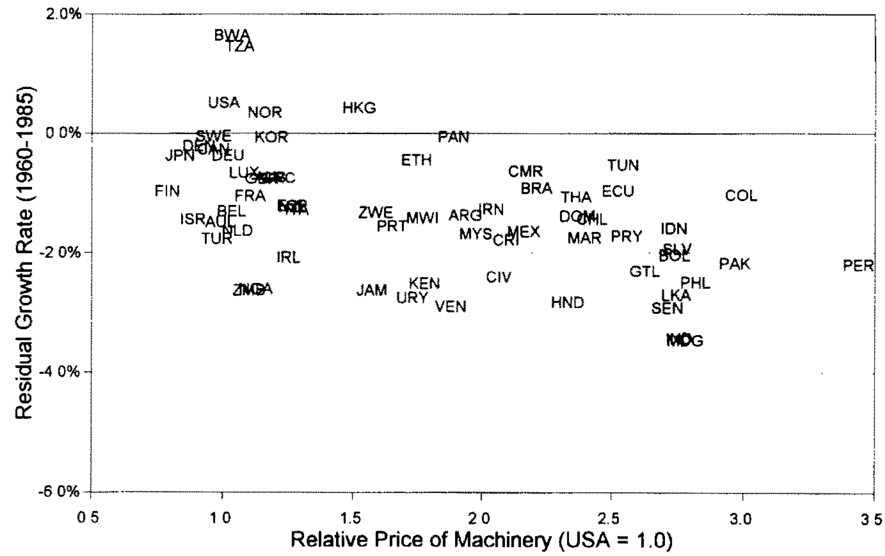

Fig. 3. Annual GDP growth vs. machinery price partial correlation ($N = 65$).

variation is related to a country's level of GDP (see Summers and Heston, 1988). One suspects that such data problems could mask the relationship between growth and relative price, but in the regression above a significant negative relationship is still evident. Nevertheless, Table 2 also reports results for various subsamples: those with an initial level of GDP greater than 10% and 20% of that in the United States. The basic result that the relative price of machinery is negatively related to growth is magnified when the country subset is further restricted. Indeed, for the 20% subset the coefficient on the relative price of machinery is -0.0195 with a standard error of 0.0048. One caveat for interpreting this result is relevant, however: because of collinearity resulting from the smaller sample size, the country characteristics variables are not included in the subset regressions. In particular, the Africa and Latin America indicator variables are omitted. Thus, to some extent the machinery price may be capturing unobserved region effects as well, or at least the data is unable to separate the two effects.

An additional explanation is plausible. As was shown in Fig. 2, the more developed countries tend to have on average lower values for the relative price of machinery. The regression results could, therefore, be suggesting that changes in the relative price that would be 'small' for the less developed countries still have a significant impact on growth when the changes occur in more developed countries. However, this hypothesis is rejected by a simple Chow test: when an interaction term between the price of machinery and an indicator variable for developed countries (those with GDP greater than 20% of U.S. GDP in 1960) is included, it enters with a small and insignificant coefficient. This makes the former explanation seem more likely.

In addition to considering various subsamples of countries, different time periods are also examined. The middle panel of Table 2 presents the regression results when the growth rate from 1960 to 1975 is used, and the final panel reports similar regressions when the 1970–1985 period is considered. This sensitivity analysis provides some evidence that using the relative price data from 1980 is not the crucial factor driving the results. The results for the relative price variable are strong in all subsamples when the 1960–1975 period is considered. For the 1970–1985 period, though, the relative price enters significantly only when the 20% subsample is used. Possibly, this reflects some of the measurement error problems. Another explanation also seems relevant. This latest period was marred by two oil shocks and ended with a recession for many countries; consequently, many countries had average annual growth rates that were actually negative. This, together with the fact that 1970–1985 is a relatively short period, could account partially for the less robust results.

3.2. *Growth and other price variables*

Table 3 presents the regression results when the other relative price variables are included in the basic specification. The main result of this table is summarized in the first row, where nonmachinery investment denotes all investment other than the machinery component. When the relative price of machinery and the relative price of nonmachinery are included together, the coefficient on the nonmachinery price is only 0.0001, with a standard error of 0.0026. In stark contrast, the coefficient on the machinery price is unchanged from Table 2 and highly significant. In terms of the relative price of capital, then, the machinery component is clearly the driving force behind growth.

The remainder of Table 3 illustrates the robustness of this result by including a single relative price measure for various subaggregates of investment. When relative prices for either total investment or nonmachinery investment are included individually, the coefficients are negative but insignificant. Total investment can be split into construction and producer durables. The construction relative price (only nonresidential is reported but the results are the same for residential and for total construction) has a negative coefficient, but its standard error is larger in magnitude. In contrast, the producer durables relative price enters negatively and significantly. The producer durables component consists of transportation equipment, electric machinery, and nonelectric machinery, and the final rows of Table 3 report the regression results when the relative price for each of these variables is included separately. The two machinery relative prices enter negatively, while the transportation equipment variable enters

Table 3
Growth and the subaggregates of capital formation – Dependent variable: annual growth rate of GDP per capita, 1960–1985

Relative price variable	Relative price variable (see first column)	Relative price of machinery	S.E.E.	R^2
Nonmachinery investment	0.0001 (0.0026)	– 0.0076 (0.0034)	0.0101	0.68
Nonres. construction (N = 60)	0.0008 (0.0016)	– 0.0086 (0.0039)	0.0105	0.68
Transport equipment	0.0018 (0.0011)	– 0.0095 (0.0041)	0.0100	0.69
Total investment	– 0.0056 (0.0039)	—	0.0104	0.66
Nonmachinery investment	– 0.0027 (0.0034)	—	0.0106	0.64
Nonres. construction (N = 60)	– 0.0012 (0.0022)		0.0111	0.63
Producer durables	– 0.0058 (0.0032)	—	0.0103	0.66
Transport equipment	– 0.0013 (0.0012)	—	0.0106	0.61
Electric machinery	– 0.0040 (0.0023)		0.0103	0.67
Nonelectric machinery	– 0.0076 (0.0035)	—	0.0101	0.68

The sample size is 65 countries unless noted. The 'relative price variable' in the second column differs in each regression and is given by the first column. A constant term, the country characteristics variables, and the Barro (1991) variables included in Table 2 were included in each specification. White heteroskedasticity-robust standard errors are reported in parentheses.

insignificantly. Once again, the results highlight the importance of the machinery component of investment.

Table 4 documents the robustness of the results in three further directions. The first regression in Table 4 reports the basic result for the relative price of machinery in the 56-country sample for which 1980 benchmark data are available. The next two regressions in Table 4 illustrate that the relative price of machinery outperforms the absolute price. When both the absolute and relative prices are entered together into the Barro specification, the coefficient on the

Table 4
Checks for robustness – Dependent variable: annual growth rate of GDP per capita, 1960–1985 ($N = 56$)

Price variable	Price variable (see first column)	Relative price of machinery	S.E.E.	R^2
Basic result for the 56-country sample with 1980 benchmarks	–	– 0.0095 (0.0045)	0.0104	0.69
Absolute price results				
Machinery (absolute price)	– 0.0095 (0.0058)	—	0.0109	0.66
Machinery (absolute price)	– 0.0052 (0.0046)	– 0.0082 (0.0044)	0.0104	0.70
Alternative consumption deflators				
1980 machinery price divided by 1960 consumption price	– 0.0045 (0.0020)	—	0.0107	0.67
1980 elect. mach. price divided by 1960 consumption price	– 0.0036 (0.0017)		0.0106	0.68
1980 nonelec. mach. price divided by 1960 consumption price	– 0.0043 (0.0016)	—	0.0107	0.68

Results are based on the original sample of 56 countries using 1980 benchmark data. The 'price variable' in the second column differs in each regression and is given by the first column. Relative prices have been divided by a consumption deflator; absolute prices have not. A constant term, the country characteristics variables, and the Barro (1991) variables included in Table 2 are included in each specification. White heteroskedasticity-robust standard errors are reported in parentheses.

absolute price falls in both magnitude and significance, while the relative price maintains its size and significance. Similar results can be obtained with the other components of the relative price of capital.

Another potential problem with the relative price of machinery is that it is calculated using the benchmark consumption price data for 1980. At least since Balassa (1964) it has been known that the price of nontradables is positively related to the level of development, so that one explanation for the success of the relative price variable could be that the 1980 value of the consumption deflator is contaminating the results. The final three regressions of Table 4 address this concern. For the machinery aggregate as well as for its nonelectric and electric components, replacing the 1980 deflator in the denominator with the 1960 consumption deflator from the Penn World Tables Mark 4 does not change the basic results.[9]

3.3. Investment and the relative price of machinery

Thus far, the channel through which the relative price of machinery affects growth has been assumed but not discussed. Presumably, an increase in the relative price of machinery reduces capital accumulation and therefore reduces the growth rate of the economy. Table 5 explicitly examines the relationship between the relative price of machinery and investment. If one assumes an open economy model in which the supply of capital to small countries is perfectly elastic, then a regression of investment on the relative price of machinery will trace out a demand schedule. In Table 5, the relative price of machinery enters negatively with a very small standard error. This is true whether the left-hand-side variable is the average total investment share in GDP for 1960–1985, average total investment for 1970–1985, or the machinery investment share for 1980.

While the result for the machinery investment share needs no explanation, it is slightly puzzling, perhaps, that the results for total investment are so strong. Several explanations are possible, but according to other regression results that are not reported, one seems likely. Other regressions with the total investment share on the left-hand side included the machinery share of investment and the relative price of total investment, both individually and together. Both of these variables were always significant and had the expected sign. When the relative price of machinery was included with either of these other variables, they still retained their significance. However, the relative price of machinery also entered significantly. This suggests that much of investment may in fact be driven by machinery investment. Holding fixed the relative price of total investment or the share of machinery investment, a higher relative price of machinery investment reduces the total investment share. The relative price of machinery is crucial for determining not only the share of investment devoted to machinery, but also for determining the total share of investment within an economy.

3.4. Empirical results using other price distortion measures

Because of the potential problems with the relative price variables that were mentioned earlier, I have constructed several other 'price distortion' measures in

[9]The apparent decline in the magnitude of the effect is somewhat overstated because the price variable itself is different. The standard deviation of the relative price of machinery calculated using the 1980 benchmark consumption deflator is 0.73; the standard deviation using the 1960 deflator is 0.95. Thus a one-standard-deviation increase in the 1980 based measure is associated with a decline in growth of 0.70 percentage points, while a one-standard-deviation increase in the 1960-based measure is associated with a decline in growth of 0.42 percentage points.

Table 5
Investment rates and the relative price of machinery

Dependent variable	Initial GDP per capita	Initial secondary school E.R.	Initial primary school E.R.	Avg. govt. consumption/ GDP	Relative price of machinery	S.E.E.	R^2
Total investment share of GDP, 1960–85 avg.	−0.0132 (0.0054)	0.0849 (0.0559)	0.0727 (0.0298)	−0.0655 (0.1041)	−0.0581 (0.0114)	0.0499	0.61
Total investment share of GDP, 1970–85 avg.	−0.0172 (0.0051)	0.0629 (0.0589)	0.0619 (0.0302)	−0.0678 (0.1133)	−0.0666 (0.0133)	0.0498	0.59
Machinery investment share of GDP, 1980	−0.0033 (0.0021)	0.0053 (0.0210)	−0.0108 (0.0107)	−0.0299 (0.0427)	−0.0293 (0.0063)	0.0180	0.63

A constant term and the following country characteristics variables taken from Barro (1991) are suppressed in the results: war indicator variable, number of revolutions during 1960–1985, socialist government indicator, and indicator variables for the Latin American and Sub-saharan Africa regions. White heteroskedasticity-robust standard errors are reported in parentheses.

an attempt to confirm the results obtained with the relative price data. The first of these price distortion variables is the average share of revenue generated by tariffs in central government revenue for 1976–1978, the earliest period for which data on a large number of countries could be obtained. The data for this variable is taken from the IMF's *Government Finance Statistics*.

The second distortion variable is the effective rate of protection in the manufacturing sector (ERP). Two steps were used to obtain an estimate of the effective rate of protection in each country. First, a wide variety of sources were consulted, yielding estimates of the effective rate of protection for various years during the 1960–1985 period.[10] Unfortunately, these data were generally only available for a single year for any given country. The few cases in which estimates were available from different studies for the same country highlight the problems with this data. For example, Yeats (1976) reported a high and a low estimate for the effective rate of protection in Iran during the period 1963–1968 of 153 and 53, respectively. Similarly, two different studies reported values of 61 and 20 for the effective rate of protection in Mexico in 1960. Despite these problems, the first step in constructing the ERP variable was to obtain an arithmetic average of the estimates found in the literature.

The second step exploited the high correlation between the effective rate of protection and the nominal rate of protection that has been noted by several authors, e.g., Leamer (1988).[11] Average tariff rates (mostly for manufactured and related products) acquired during the search for effective rates of protection were used to extend the sample for which ERP is available. Average tariff rates were obtained for 34 countries, 11 of which did not also have an associated ERP number. These two variables are highly correlated (the sample correlation is 0.93), and a regression of the preliminary effective protection rate series on a constant and the average tariff rates was used to 'fit' values of ERP for the 11 additional countries. This method produced the final version of the effective rate of protection series, which covers 51 countries in this sample.

Finally, Agarwala (1983) used a similar method to consider the effect of price distortions on economic growth. Noting the general problems with using the effective rate of protection data mentioned above, he reduced his series of effective rates of protection to a qualitative indicator variable. This variable took the value of 'high' if the effective rate of protection in a country was greater than 0.80, 'medium' if it was between 0.40 and 0.80, and 'low' if it was less than 0.40. Following Agarwala, an indicator variable was constructed taking values of 0, 1, and 2 to represent low, medium, and high effective rates of protection.

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[10] A complete bibliography of these sources is available from the author upon request.

[11] The nominal rate of protection ignores the effect of a staggered tariff structure which alters the price of inputs as well as the price of the final good. Thus, it is simply equal to the ad valorem tariff rate.

Needless to say, each of these variables is extremely problematic as a measure of price distortion. Indeed, this is one of the basic reasons why the relative price variables from the Summers and Heston data set are so appealing. However, these additional measures permit independent confirmation of the basic hypothesis of this paper. The results of including these variables in the growth regression are presented in Table 6, and a tentative confirmation is indeed obtained as these variables enter negatively with varying degrees of (in)significance.

3.5. *Measurement error, endogeneity, and instrumental variables correction*

Several aspects of the empirical model estimated above suggest that measurement error may be a problem, particularly for the relative price variables. The basic quality of the data is questionable, especially for the low-income countries included in the sample, although this is likely to be less important since only countries participating in benchmark surveys are included. In addition, because the relative price of machinery is taken from data at the end of the sample period instead at the beginning, there exists a basic question about endogeneity and causality.

In an attempt to address these issues, the alternative price distortion measures discussed above are employed as instruments. These instruments are correlated with the relative price variables but are likely to be uncorrelated with the error in measurement. Because the variables are constructed using data from throughout the period, they are also less likely to be endogenous. Clearly, these instruments are themselves measured with error. However, as long as the error in measurement for the instruments is asymptotically orthogonal to the error in measurement for the relative price of machinery, consistent estimates will be obtained.

The results of IV estimation treating the relative price of machinery as endogenous are presented in Table 6. Similar estimation is also undertaken using the ERP indicator variable instead of the relative price of machinery (clearly, the ERP indicator variable is measured with error). In all of the IV regressions, the price variable has the appropriate negative sign. However, the standard errors are generally large, particularly for the relative price of machinery. Hausman (1978) specification tests were conducted, but because of the large standard errors, the null hypothesis of no measurement error could never be rejected. In the end, nothing in the IV regressions is particularly surprising, but no strong results are obtained.

3.6. *Endogeneity and a comparison to the De Long and Summers (1991) results*

The basic finding of De Long and Summers (1991) is that the share of machinery investment (which they call 'equipment investment') in GDP is a crucial determinant of economic growth. The results discussed above are

Table 6
IV estimation and other price distortion measures – Dependent variable: annual growth rate of GDP per capita, 1960–1985

Price distortion variable	Initial GDP per capita	Initial secondary school E.R.	Initial primary school E.R.	Avg. govt. consumption/ GDP	Price distortion variable	S.E.E.	R^2
OLS estimation							
Tariff revenue share	– 0.0070	0.0106	0.0127	– 0.1174	– 0.0167		
(N = 51)	(0.0013)	(0.0082)	(0.0069)	(0.0318)	(0.0115)	0.0096	0.69
Effective rate of	– 0.0069	0.0129	0.0108	– 0.1251	– 0.0042		
protection (N = 51)	(0.0013)	(0.0089)	(0.0074)	(0.0318)	(0.0033)	0.0095	0.70
ERP indicator	– 0.0070	0.0102	0.0088	– 0.1214	– 0.0062		
(N = 51)	(0.0013)	(0.0083)	(0.0074)	(0.0300)	(0.0026)	0.0090	0.73

Instrumental variables estimation							
Relative price of machinery[b,c] ($N = 46$)	−0.0055 (0.0013)	−0.0052 (0.0110)	0.0072 (0.0056)	−0.0980 (0.0296)	−0.0066 (0.0046)	0.0085	—
Relative price of machinery[a,c] ($N = 46$)	−0.0054 (0.0013)	−0.0033 (0.0115)	0.0078 (0.0059)	−0.1020 (0.0308)	−0.0052 (0.0049)	0.0082	—
ERP indicator[a] ($N = 51$)	−0.0069 (0.0013)	0.0110 (0.0087)	0.0096 (0.0074)	−0.1227 (0.0305)	−0.0048 (0.0034)	0.0090	-
ERP indicator[a,c] ($N = 51$)	−0.0069 (0.0013)	0.0112 (0.0087)	0.0097 (0.0074)	−0.1229 (0.0305)	−0.0045 (0.0034)	0.0089	—
ERP indicator[a,d] ($N = 51$)	−0.0052 (0.0013)	0.0025 (0.0088)	0.0088 (0.0062)	−0.1138 (0.0279)	−0.0025 (0.0032)	0.0077	—

A constant term and the country characteristic variables listed in Table 2 are suppressed in the results. White heteroskedasticity-robust standard errors are reported in parentheses. In the IV estimation regressions, only the price distortion measure is assumed to be endogenous. The instruments used in each regression (whose construction is discussed more fully in the text) are listed as superscripts with the following meanings:

[a]Effective rate of protection (ERP).

[b]ERP indicator variable.

[c]Tariff revenue share in total revenue.

[d]Relative price of machinery.

consistent with those obtained by De Long and Summers but extend and clarify their analysis in several important ways. The primary difference is that this paper focuses on the estimation of the relative price effect on growth while De Long and Summers focus on the quantity effect. Estimation of the relative price effect is likely to be more useful for two key reasons. First, it is more immune to endogeneity arguments than is the estimation of the quantity effect. And second, because policy instruments work through prices to affect the quantity of investment and the rate of growth, estimating the link between prices and growth is more useful from a policy standpoint. Each of these issues is discussed further below.

De Long and Summers focus primarily on the relationship between economic growth and the share of machinery investment in a sample of 25 'high-productivity' countries.[12] While this relationship is of interest, issues of endogeneity make it a problematic relationship to analyze. The converse of their conclusion may well apply: economic growth could result in a higher share of machinery investment in total output rather than vice versa. This endogeneity could lead De Long and Summers to overstate the effect of machinery investment on growth.[13]

In an open economy model, this 'reverse causality' argument will not affect the analysis here. Because of the open economy assumption, economic growth will increase the machinery investment share only through the demand side. These demand side effects will not change the price of machinery, which is exogenously given by the world price plus any price distortions. However, changes in the price of machinery (e.g., due to a change in government policy) will still affect machinery investment and hence the rate of economic growth. Thus, focusing on the price instead of the quantity successfully addresses these endogeneity issues in an open economy framework.

In a closed economy model, the 'reverse causality' argument can be understood in terms of two nonexclusive effects: economic growth increases the share of investment in output by raising either the demand for investment or the supply of investment. If economic growth increases investment demand,

[12]When De Long and Summers do examine the effect of the relative price of machinery on growth, their results are unclear. The only significant and negative coefficients arise when the restricted 'high-productivity' sample is considered. However, they only estimate the price effect when a variable measuring the share of investment in GDP is included in the regression. Since I have argued above that it is exactly through this channel that the relative price of machinery influences the growth rate of the economy, their results are not surprising. My analysis reveals that when this investment variable is removed from the specification, a strong negative relationship between the price of machinery and economic growth emerges, not only for a small sample of 'high-productivity' countries, but also for the broadest sample available using the Summers and Heston benchmark data.

[13]De Long and Summers make several arguments that endogeneity is not driving their results, including the use of the relative price as an instrument.

one would expect to find a positive relationship not only between growth and the quantity of investment, but also between growth and the price of investment, *ceteris paribus*. To the extent that this type of endogeneity is a problem, my results will be biased in a positive direction – i.e., they understate the true impact of relative price movements on growth. However, if economic growth increases the supply of investment goods, the quantity of investment will rise and the price will fall, suggesting that my results for the price of investment are negatively biased and overstate the true impact of capital taxation on growth.

The net of these two effects in a closed economy model is that reverse causality will produce an unambiguous positive correlation between growth and the quantity of investment. This makes the identification of the impact of machinery investment on economic growth which De Long and Summers attempt to estimate extremely difficult. However, these two effects bias the estimated partial correlation between growth and the price of investment in opposite directions, so the net bias will be ambiguous. Furthermore, to the extent that an open economy model applies, the magnitude of this ambiguous bias will be reduced, while the positive bias in the growth–investment relationship will persist. In this context, it is clear that focusing on the price of investment rather than the quantity is preferable.

Estimation of the price effect instead of the quantity effect is important in its own right for another reason. From a policy standpoint, the magnitude of the price effect is arguably more useful than the magnitude of the quantity effect. Policy instruments such as tax rates and investment tax credits have a direct interpretable effect on the relative price of capital.[14] However, the effect on quantity variables is indirect and more difficult to estimate, so that understanding the relationship between growth and the relative price of capital provides the crucial link between policy and growth. This advantage is exploited in the next section.

4. The dynamic effect of changes in the tax treatment of machinery

The estimates computed above provide a direct measure of the effect of a change in the relative price of machinery on the growth rate. Coefficients range from a low of about -0.0075 to a high of about -0.0150 or even -0.0200. Taking -0.01 as an approximate value does not seem implausible, and this implies that a unit increase in the relative price of machinery will reduce the

[14]The only potential problem with interpretation here is in knowing how much of the tax or subsidy is borne by the producer and how much is borne by the consumer. We abstract from this important issue here.

average annual growth rate of the economy by a full percentage point. Recall from Table 2 that this value may slightly overestimate the effect for a less developed country like India and slightly underestimate the effect for a more developed country such as the United States. Nevertheless, it serves as a useful benchmark for the comparison of different policies.

While knowledge of these coefficients is very helpful, a necessary piece of information that is absent from this analysis is the current tax treatment of machinery. One would like to know how changing the tax rate (or subsidy rate) on machinery will affect the growth of the economy, and for this specific information about the tax rates in a given country is required.

Ahmad and Stern (1987) present a very detailed view of the tax system in India for 1979–1980, including a table of effective tax rates for specific categories in the national accounts. The effective tax rate takes into account both indirect and direct taxes, which Ahmad and Stern argue is crucial to an understanding of the tax system in most developing countries. Using their data it is straightforward to construct an effective tax rate for machinery for the 1979–1980 period, and my calculations yield an effective tax rate of 0.218.[15] Simple manipulation reveals that absent these taxes the relative price of machinery would have been lower by 0.5.[16] Given a coefficient of −0.01 on the relative price variable in the growth regression, this suggests that the tax on machinery was responsible for reducing growth in India by approximately one-half of a percentage point. Since the average annual growth rate for 1960–1985 was only 1.4%, the effective tax on machinery had a substantial effect on growth.

Countries such as India with a high relative price of machinery have the most to gain from a reduction in proportional capital taxation, as the following example illustrates. Consider an investment tax credit in the United States, which had a per capita GDP of $12,532 in 1985. Growing at its 1960–1985 average annual growth rate of 2.1%, per capita GDP will reach $21,185 by the year 2010. Now suppose an investment tax credit of 10% was introduced. Using the rather pessimistic coefficient of −0.01 for the effect of the relative price of machinery on growth, U.S. GDP would grow at 2.2% each year to a level of $21,721 in 25 years. With a more optimistic coefficient of −0.02, the growth rate of output would be raised to 2.3%, and U.S. per capita GDP would reach

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[15]The effective tax rate, as defined by Ahmad and Stern, includes main central government taxes, excise taxes, import duties, and state level taxes. It excludes taxes on capital inputs to production, which will cause the measured effective tax to understate the true effective tax.

[16]According to the benchmark data, the relative price of machinery in 1980 was 2.76. Absent the taxes the relative price of machinery would have been 2.27.

\$22,271 by 2010 – more than \$1,000 more per person.[17] This change is not as dramatic as that for India or other high-price countries, but it is by no means negligible.

5. Conclusions

The effect of price distortions on the growth rate of an economy will most certainly depend on the context in which the distortions are imposed. However, in this empirical analysis of a broad cross-section of economies, a result which emerges consistently is that distortions in the relative price of capital, especially the machinery component, are associated with low growth over the period 1960–1985. Policies that decrease the relative price of machinery increase the share of investment in gross domestic product, not only by raising machinery's share in output, but also by increasing other components of investment. Thus it remains to be determined whether machinery investment is itself a key component of economic growth or whether the relative price of machinery is just a particularly good indicator of distortionary policies in general. In either case, price distortions appear to be robustly correlated with poor growth performance.

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[17] Ideally, one would like to consider revenue neutral changes in the tax code. Implicitly, we are assuming that the revenue lost from an investment tax credit or from reducing the tax on machinery would come from a source that would not affect the growth rate substantially.

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