TAXES AND THE QUALITY OF CAPITAL

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Abstract

This paper shows that tax policy toward investment, by changing the relative prices of capital varieties even within narrow classes of equipment, can have a direct effect on the quality composition of capital goods that firms purchase. Detailed data on farming, mining, and construction machinery suggest that this impact may be economically important. Firms shift investment toward higher quality varieties when they receive investment subsidies but do not do so when investment is high for other reasons. In the aggregate, the data suggest that all of the new investment generated by tax subsidies comes from firms shifting to higher quality capital goods rather than buying a larger number of their existing capital types. The paper also applies a methodology for calculating the implied deadweight loss from the quality distortion and shows that its magnitude may represent a substantial efficiency cost from capital taxation that is neglected in conventional work.

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The conventional analysis of tax policy toward investment treats capital as a homogeneous good and asks how much investment responds to the cost of capital.[1] This approach, however, does not do justice to the heterogeneity of actual capital goods. In reality, buyers of capital must choose between heavily differentiated products even within relatively narrow classes of assets, routinely deciding not just how much capital to buy but also what type and what quality of capital to buy. The choices that firms make about technology and quality when they are embodied in the capital goods can be important for macroeconomics, growth theory, and the measurement of productivity.[2] If taxes were to affect quality change, this could be important for empirical work on investment.

There is, however, virtually no empirical work on the subject of taxes and the quality of capital. Indeed there is very little work relating taxes to the quality of any good.[3] This lack of empirical work on taxes and quality is somewhat surprising for the case of capital specifically, since important theoretical contributions were made early on in related areas such as how inflation and corporate taxes can affect the choice of asset durability.[4] The lack of data at a sufficient level of detail is almost certainly to blame.

In a conventional model, changing the cost of capital leads the firm to change it capital-labor ratio by expanding the capital stock. There are ways, however, that tax policy may alter this basic incentive. It can lead them not just to buy more capital but instead to change the type of capital they buy. One simple reason tax policy might affect choices about the quality of investment is that investment taxes apply only to direct investment spending and not to things like future maintenance,

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[1] A recent survey of conventional investment approaches can be found in Chirinko (1993). Work that applies conventional analysis but to disaggregated types of investment includes Auerbach and Hasset (1991) and Goolsbee (1998a).

[2] Empirical work concerning the importance of heterogeneous capital includes Goolsbee and Gross (1999), Ramey and Shapiro (1998, 2000) among others. Grossman and Helpman (1991) demonstrate the importance that quality change can have for the study of growth. In macroeconomics and investment, the importance of capital vintage and heterogeneity can be found in recent vintage capital models such as Greenwood, Hurcowitz, and Krusell (1997), Caballero (1997), or Jovanovic (1998). Discussions of the issues that quality change raises for the productivity literature can be found in Gordon (1990) or Griliches (1994).

[3] An exception is the work on cigarettes found in Sobel and Garrett (1997) and, indirectly, Barzel (1976), Johnson (1978), and Sumner and Ward (1981) as is the work on automobiles of Fershtman, Gandal, and Markovich (1999). Further, there is important, related, work on the quality effects of import quotas such as Boorstein and Feenstra (1991), Feenstra (1988; 1993; 1995) or Anderson (1986).

[4] Early work on inflation and the choice of durability includes Auerbach (1979), Abel (1983). Early work on corporate taxes and durability includes Feldstein and Rothschlid (1974), Sandmo (1974), or Raviv and Zemil (1977).

worker training, or machine supervision which may be substitutes for initial quality. As a result, tax policy can alter the relative price of high versus low quality goods, encouraging firms to buy cheaper capital with greater maintenance costs, for example, when taxes are high.[5]

This paper examines the role of tax policy on the quality of capital investment using data on the prices, maintenance costs, and quantities of highly disaggregated capital varieties of mining, construction, and farm machinery and by adapting empirical methods from the international trade productivity literatures on index number theory to measure changes to the quality composition of investment and calculate the deadweight loss of tax induced quality distortions.

The results suggest that there is a relatively robust cross-sectional evidence that when investment is subsidized, investment does not expand symmetrically. Shipments of higher priced varieties of capital increase more than those of lower priced varieties. This shift into higher quality types of capital, however, is not a general feature of investment during booms or other high investment periods, only of tax induced investment. There are several viable sources of this tax-quality composition effect. Direct industry data on one of them—per unit maintenance expenses that are higher for lower quality machines (even within narrow equipment categories)—confirm the existence of such a mechanism and with a magnitude large enough to explain the results.

In the aggregate, all of the increase in investment from a tax subsidy comes about from an upgrade in the quality of capital purchases, not from an increase in the physical quantity. When investment is subsidized through the tax system, firms expand the capital-labor ratio by shifting to more expensive machines rather than by expanding the number of machines. Further, the true price index for capital also rises in response to investment subsidies, suggesting an upward-sloping supply of capital with an elasticity of around one.

These tax induced changes to the quality composition of investment creates a deadweight loss that may be considerably larger than conventionally estimated (i.e., without accounting for quality change), amounting to as much as 20% of the revenue spent on an investment subsidy or raised from a tax.

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[5] This idea is similar to the Alchian-Allen theorem that constant transportation costs change relative prices and thereby raise the average quality of imports (see Borderching and Silberberg, 1978) and also the work of Barzel (1976) showing that taxes, by applying to goods rather than the characteristics of goods, can induce changes to the included characteristics of those goods. It is also related to the international trade literature on quotas and quality upgrading such as Falvey (1979), Rodriguez (1979), Das and Donnenfeld (1987), and Krishna (1987).

The paper proceeds in six sections. Section II discusses the basic theoretical idea of the paper. Section III discusses the data and presents the cross-sectional evidence on the relation of taxes and quality. Section IV develops a rigorous approach to aggregating the data. Section V presents these aggregate results. Section VI derives a measure of the deadweight loss arising from quality change and calculates its magnitude. Section VII concludes.

II. A Simple Model

The paper will look for the effect of taxes on quality changes in the choice of investment goods. Although investment tax policy is basically ad valorem, intuition for why it could change relative prices of different varieties centers on a simple fact of the tax system: tax policy applies only to the purchase and installation of a capital good. Future costs such as the repairs and maintenance required to keep it functioning are generally not depreciated over time as is the purchase cost is although they are part of the economic concept of the good's price. Instead, these future costs are expensed when they occur. To the extent that higher quality goods have different levels of future direct expenses, changing the tax treatment of investment (relative to direct expensing) will effectively apply different tax or subsidy rates to different types of capital. This will be true for any factor associated with the capital that is directly expensed. The higher quality goods could have different training requirements, different labor requirements, different maintenance, or they could have different asset lives.

To illustrate this intuition, consider the simplest possible world in which there are two types of capital (denoted type 1 and type 2). The relative demand function for the goods, h, depends negatively on the relative costs but the true purchase cost of each good is the sale price, P, plus the present value of required maintenance and other future expenses per unit, M. Good B is of higher quality than good A meaning its ratio of future maintenance expenses to its sale price is smaller (i.e. $M_B/ P_B> M_A/P_A$).

Assume that the future maintenance costs are directly expense and, for simplicity, that there is no corporate income tax. The purchase price is not expensed but does receive some investment subsidy at rate *s*. The relative demand for the higher quality product (where X is quantity) becomes

$$\frac{X_A}{X_B} = h\left(\frac{M_A + (1-s)P_A}{M_B + (1-s)P_B}\right) \qquad (1)$$

and therefore

$$\frac{\partial\left(X_A \big/ X_B\right)}{\partial s} = h'(\cdot)\left(\frac{M_A P_B - M_B P_A}{(M_B + (1-s)P_B)^2}\right) = h'(\cdot)\frac{P_B P_A}{(M_B + (1-s)P_B)^2}\left(\frac{M_A}{P_A} - \frac{M_B}{P_B}\right). \qquad (2)$$

So long as $M_B/ P_B > M_A/P_A$, the derivative is greater than zero. In words, increasing the subsidy for investment lowers the price of the high quality good relative to the low quality good and leads to quality upgrading because subsidizing the purchase price leads the firm to buy higher priced capital that doesn't need repairs. As the aggregation section will show below, allowing for multiple capital goods does not change this main idea so long as the cross-price effects satisfy reasonable conditions.

It is important to note that the sign on the derivative in (2) depends on the assumption that higher quality varieties have lower future maintenance or other expensable costs per unit. Standard capital data, even highly disaggregated do not provide a direct measure of quality or future expenses for a capital variety or the embodied capital-labor ratio in that equipment, only its initial price per unit which will serve as a proxy. It will be important, therefore, to establish that such capital actually does differ in at least some relevant dimension. For that I will incorporate information from industry sources on maintenance and repair costs for specific capital goods.

III. Data and Cross-Sectional Results

A. Data on Capital

To look for tax induced quality changes requires data on the prices and quantities of highly disaggregated capital goods and such data are rare. The Bureau of the Census does, however, issue the *Current Industrial Reports* (*CIR*) which provide, for a select number of domestic sectors, disaggregated data on the value and quantity produced. The *CIR* program is meant to complement the Census of Manufacturers and the Annual Survey of Manufacturers by looking at prices and quantities at the seven digit SIC code level–a greater level of detail than in a standard census. The

*CIR*s' primary objective is to provide "timely, accurate data on production and shipments of selected products" and they measure transaction prices, as opposed to list prices. A description can be found in Bureau of the Census (1995) and more details are given in Appendix A. The results use information on three different *CIR* classes of equipment: construction machinery, mining and mineral processing machinery, and agricultural machinery. Unfortunately, the data are just on shipments of capital goods (i.e., investment) rather than capital stock so it impossible to distinguish between net investment and replacement investment as in the work of Goolsbee (1998b), Ramey and Shapiro (1998), or Whalen (2000).

Every *CIR* gives, for each product sub-variety, the number of units produced and the total value of those units. The price (or unit value) is simply the total value divided by the total number of units. On average there are about 50 usable product varieties per year for Mining machinery, 80 varieties for Construction machinery, and 150 varieties for Farm equipment in the respective *CIRs*. Table 1 gives summary statistics of the real price distributions in 1987 dollars for the full sample. The mining and construction machines are generally much more expensive pieces of equipment than are the farm machines.

Unit value data have been criticized in the productivity literature for providing inadequate long-run measures of quality change because even the seven digit product codes of the *CIR* often cover different goods and tend to mask quality changes within category (see Griliches & Lichtenberg, 1989 or Gordon, 1990). These same sources, however, point out that the advantage of the unit value data lies in their improved short-run accuracy because they are based on transaction prices; I will use them only to look at short-run changes to investment composition. This is an unfortunate drawback of the data since it precludes estimating the important long run-effects on quality change as well as determining whether observed changes to quality are merely timing shifts in the sense of Slemrod (1995) or Goolsbee (2000a). On the positive side, however, since the goal of this paper is to examine the role of taxes on the quality composition of investment, the problem of within product class quality change will tend to bias the results away from finding tax effects, even if they exist.

It is necessary at the outset to eliminate potential confusion over the meaning of quality change. As discussed in Feenstra (1995), quality upgrading can mean two different things–a shift in the composition of demand toward higher priced varieties or the addition of new characteristics to existing varieties. The two notions are complementary but data constraints usually require one approach or the other.[6] My focus will be on the former approach–testing whether the sales of more expensive (higher quality) capital varieties increase relative to cheaper varieties when investment spending is subsidized.[7] This view of quality composition is fundamentally a demand side phenomenon, holding the attributes of existing products fixed. This is likely to be more accurate in the short run, which will be the focus here, but better data would allow for a longer run perspective to determine whether suppliers react to subsidies as well.

The basic issue is how investment responds to tax policy. The conventional approach suggests that subsidies lead firms to expand capital generally—in the disaggregate data, this would be an expansion of investment but in equal proportions for the various types of capital. The theory of this paper suggests that the subsidies should give more stimulus for certain types of capital than for others so the expansion should lead to a change in the quality composition. Table 2 gives a concrete example of quality change using a subset of the varieties of mining and mineral processing machinery for 1981 (a tax cut year). This table lists varieties of "Underground Mining Machinery" (SIC code 35235), arranged by per-unit price in 1980. The table shows the percentage change from 1980 to 1981 in the number of goods shipped and the share of total value accounted for in 1980 and 1981 by each variety. In this year, total investment spending rose substantially. It was not evenly distributed, however. Output generally rose a lot for the high priced varieties but actually fell for the low priced ones (and similarly for the shares of total value accounted for by the various types).

Although the level of detail examined here is much greater than in the conventional investment research, one might argue that the specific products listed are not perfect substitutes and some may even be complements. To the extent that the types of mining machinery are not substitutes, however, this should tend to lead the results toward finding small effects of taxation on quality change. Later I will present calculations as to what the results imply for the elasticity of substitution between capital varieties within the broader classes of assets.

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[6] The first approach has been used to study the effects of import quotas on the quality of imports such as Anderson (1985), Aw and Roberts (1986), and Boorstein and Feenstra (1991). Examples of the second approach using hedonic methods include Gordon (1990) and Feenstra (1988).

[7] I will present direct evidence that the higher priced varieties do, indeed, have lower relative repair costs.

To examine the role of taxes, I match the *CIR* data to the tax price of investment spending relative to expensing. This is the familiar contemporaneous tax cost of capital formula, (1-ITC-tz)/(1-t), where ITC is the investment tax credit, t is the corporate tax rate, and z is the present value of depreciation allowances. The data were provided for each of the three broad asset categories by Dale Jorgenson and more details on them can be found in Jorgenson and Yun (1991). The results that follow include other control variables such as the real baa bond rate, the GDP growth rate, a variable for the Nixon price controls, the ratio of equipment investment to GDP, and year dummies. Real prices are deflated by the GDP deflator. All the macroeconomic variables come from *The Economic Report of the President.*

B. Are Unit Prices Actually Correlated With Quality?

In the example above, I characterize quality change as a shift to higher priced varieties. For the argument of this paper to work, however, it must be the case that the higher priced varieties actually have lower relative future expenses per unit than do the lower priced varieties. These future expenses could be different embodied capital-labor ratios for different types of machines, different training costs, or many other things. Unfortunately, the *CIRs* do not contain this type of information, nor do other government data sources. Industry sources, however, do keep information on one of the most plausible costs—maintenance and repair. These data indicate that higher priced capital varieties have notably lower per unit maintnance expenses.

Evidence on this relationship for construction machinery and for mining machinery comes from the *Contractors' Equipment Cost Guide* (1999) released by Primedia Information's Machinery Information Division (K-III) in cooperation with the Associated General Contractors of America. Data on agricultural machinery comes from a software program called AGMACH$ that is used in the industry to forecast operating costs (in both cases, there is no available information from the time period examined in the study so I rely on 1999 cost estimates and assume the same relationship held during the time period of the *CIR* data).

. The construction and mining machinery data include more detail than the *CIR*s, going down even to the manufacturer and the model number. There are 83 equipment types of mining machinery with 1082 model varieties. There are 541 equipment types of construction machinery with 4449 model varieties. For farming machinery, the data are different and less detailed. In them there are 4 equipment categories with 39 equipment types and no more detailed model information.

I construct a net present value of future repair costs for each type of equipment, as described in appendix A. The construction and mining equipment data are much more detailed than the agricultural equipment data. Further, the agricultural data source assumes that the farmer does all the future repairs himself excludes labor costs from the calculation, leading to a substantial understatement for this group relative to the others. Since I am only concerned with the quality-price relationship within group, I do not bother to reconcile the numbers across groups. In each case, though, future maintenance expenses are a sizable share of the complete economic costs of a capital good and there is considerable variation. The median NPV of future maintenance and repairs is 104% or the base price for construction machinery and 183% for mining machinery (about 18% for agricultural machines but excluding all labor costs).

To test whether repair expenses are lower for higher priced machines, I regress the log of repair expenses for each capital good on the log of the purchase price. If the relative maintenance expenses fall for higher priced types of capital, the coefficient should be less than one. If they rise the coefficient should be greater than one. Since the data are more disaggregated than the *CIR* data, I do this in two ways. In the top panel of table 3, I include dummies for each asset type. Each of the coefficients is significantly less than one and estimated extremely precisely (the farm equipment data do not have separate models). For construction equipment, every one percent increase in the base price raises the NPV of maintenance expenses by about 0.7%. For mining machinery it raises it about 0.66%. The lower panel then re-estimates the equation using only one model per type and do not include the dummies to match the level of the *CIR* data. I choose the first model listed in each category, but this did not make any difference to the results. All three coefficients are precisely estimated and well below one (and all within the .7 to .8 range), suggesting that higher priced goods have lower future expenses.[8]

While higher priced varieties may also have lower per-unit expenses of other forms and may have higher embodied capital-labor ratios, there is no data on these factors. The data on

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[8] I also examined the relationship of base price to service lives as reported in the same data sources. The relationships were occasionally significant but always very small. Doubling the base price corresponded with capital having a 2 percent longer service life.

maintenance expenses, however, shows that there is a relationship of unit price and quality in at least this dimension. Later results will show that the quality results are plausibly explained by maintenance differences of these magnitudes.

C. Basic Cross-Sectional Results on Quality Composition Changes

The basic issue is to document what happens to the relative expenditures on higher versus lower quality varieties of capital when tax policy changes. Although it does not allow for the calculation of aggregate empirical magnitudes, the most straightforward way to document effects on the quality composition of capital is to examine the micro-level data on cross-sectional responses in years of large tax cuts and tax increases. The basic specification for a year y is then

$$\frac{\Delta q_i}{q_i} = b \ln(P_{iy-1}) + e_i \, , \tag{3}$$

where the measure of quality is P_{iy-1}, the price of type i in a year before the tax change, q is quantity, and e_i is an error term.[9] If the theory is correct that taxes have a quality impact, then running regression (3) in the year of a subsidy should yield a positive b, meaning that higher priced varieties grow faster, while running (3) in the year of a tax increase should relatively penalize the high priced varieties and create a negative b.

The first four rows of table 4 compare the b coefficients from 1981—a year with a significant drop in cost of capital—to the coefficients from 1986—a year with a significant increase.[10] I choose these two years because they are not far apart and incorporate two of the biggest tax changes in the sample but in opposite directions.

The first two rows show the results weighted by the value of shipments in the previous year. Column 1 gives results for farming machinery, column 2 for construction machinery, and column 3 for mining machinery. All the 1981 coefficients are positive and significant, indicating that higher priced machines grew faster. All the 1986 coefficients are negative, indicating the reverse. In many of the years of data, however, there are some large outliers that could be driving the results so the next two

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[9] Using the price of the variety in the previous year, the average real price throughout the sample, or the percentile distribution of the variety's price as the measure of quality made no difference to the results. The rankings are fairly stable over time.

[10] Although the Tax Reform Act of 1986 actually passed in 1987, it changed investment subsidies retroactively.

rows of the table control for their presence by doing median regressions on the same data. The results all have the same signs as in the OLS but the point estimates are larger and more significant.

While this evidence is suggestive, these two years may not be comparable because of differences in the business cycle, the interest rate, fuel prices, or a variety of other factors. To address this point, I combine all of the yearly cross-sections and test for the quality effects of tax policy while including year dummies to absorb the effect of any macro variation.[11] Since there is inflation over the time period, I compute the variety's quality as its lagged real price in 1987 dollars. These regressions test for the importance of tax policy by interacting the variety's price with the change in the tax cost of capital. The theory of this paper predicts that the coefficient should be negative since lowering the cost of capital should disproportionately increase investment in the higher priced varieties for the year.

The last two rows in table 4 present the results using OLS weighted by the value of shipments in the previous year and the results using a median regression to deal with outliers. In every case the coefficients are negative and five of the six coefficients are significant, the median regressions especially so. The magnitudes in the last row show the effects to be very similar across asset types. Instituting a 10% ITC at the mean corporate tax rate in the sample (which lowers the tax cost of capital by around .18) increases investment by an additional 5.5% every standard deviation higher is the initial price for farm machinery, 5.2% for construction machinery, and 5.4% for mining machinery.

To get a sense of the plausibility of these composition effects, I compute the implied elasticity of substitution between capital varieties by comparing the relative price change and relative quantity change for the capital goods. I do this for construction machinery where the data quality is highest, but the results were quite similar for mining machinery. The actual price of a capital type is the tax adjusted price plus the NPV of future expenses, here assumed to be strictly the maintenance expenses. If tax changes lead to large shifts in the relative amount of investment of different types of capital but the change in relative prices caused by the tax change is very small, this will imply an extremely large elasticity of substitution between capital varieties within asset group and will tend to cast doubt on the mechanism described in this paper.

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[11] These results pool the cross-sections but did not change when fixed effects for each variety were added for each 7-digit variety.

The elasticity of substitution, σ, can be approximated as the change in log relative quantities from the tax change divided by the change in the log relative price from the tax change,

$$\hat{\sigma} = \frac{Ln\left(\frac{X_1^A}{X_1^B}\right) - Ln\left(\frac{X_0^A}{X_0^B}\right)}{Ln\left(\frac{M^A + c_1 P^A}{M^B + c_1 P^B}\right) - Ln\left(\frac{M^A + c_0 P^A}{M^B + c_0 P^B}\right)}.$$

Assuming a corporate tax rate at the mean in the sample of .45, and a present value of depreciation allowances of .8, enacting a permanent unanticipated investment tax credit of 7 percent would reduce the cost of capital from 1.163 to 1.036, a difference of -0.127. According to the weighted OLS results for construction machinery at the bottom of table 4, the impact this has on the relative production of a given variety depends on its unit price. Taking a median priced capital good ($91,300 in 1998) as the base, sales of a variety with a price one standard deviation higher (worth $237,600 in 1998) would increase more. The change in log relative quantity of the two varieties from a -.127 change in the cost of capital is .030.

As for the implied change in their relative price, to calculate the change in relative prices requires calculating the change in M + cP for each one. Although c and P are observed, M is not so I use the maintenance cost regression coefficients above to impute maintenance expenses for goods of these prices. They imply a NPV of future maintenance of $122,600 for the median good and $246,800 for the higher priced good. This means that changing the cost of capital by -.127, changes the log relative price (inclusive of future expenses) of these goods by 0.007.

The implied elasticity of substitution between the varieties is, then, the ratio of these two numbers or 4.1 and this value was quite robust to the choice of varieties (the values for mining machinery were around 3). These substitution elasticities are similar in magnitude to those found between other categories of equipment such as between different aircraft models in Goolsbee and Gross (1999). This is important because it suggests that just the observed maintenance expenses are sufficient to explain the quality change results. If there are other cost differences, as seems likely, such as higher embodied capital labor ratios in the higher quality goods, then the implied elasticity of substitution between capital varieties will be even smaller.

C. Advanced Cross-Sectional Results: Alternative Explanations

The results show that in response to a tax subsidy, there is a shift in the quality composition of investment and of a plausible magnitude. Before concluding it is because of the tax code, however, it is important to consider whether this results from a spurious correlation between tax policy and other factors. A basic scale effect, for example, might imply that whenever investment is high, firms buy better machines. A Leontief production function at the micro level would generate such an outcome. Any time a firm wanted to expand the capital labor ratio, it would have to buy machines with greater embodied capital-labor ratios. All new investment generate changes in the quality composition, not just a tax induced investment. Likewise, there might be quality biased trends over time in investment which the results are confusing with tax changes. Table 5 deals with these alternative explanations. For brevity I combine all three of the capital types together and restrict the coefficients on taxes to be the same (an F-test did not reject this restriction).

The first three columns deal with the spurious trend hypothesis by comparing the change in quality for years with major tax changes to the quality change for years with minimal tax changes. If arising from a spurious trend, the observed quality shift should also appear in the years without tax changes. Column 1 shows that in years when the tax cost of capital falls by more than .05, such as 1981, investment in high quality equipment rises significantly faster. Likewise column 2 shows that in years when the tax cost of capital rises more than .05, higher quality goods are disproportionately penalized, such as in 1986. Column 3 then shows that in years in which the change in the cost of capital is small (less than .05 in absolute value), the coefficient on initial quality is also quite small.

A more detailed check for spuriousness is given in the final column which examines the role of other variables. First, column 4 combines all years in the sample and interacts the lagged real price with the change in the cost of capital and includes year dummies. This is just a repeat of the pooled regressions of table 4 but combining all three asset classes together and restricting the tax coefficient to be the same. The results show the familiar negative and significant coefficient: lowering the cost of capital raises quality.

Column 5 then repeats the same regression but also includes the lagged real price itself, an interaction of the lagged price with the real baa bond rate, an interaction with the equipment investment-to-GDP ratio and an interaction with the GDP growth rate. The lagged price alone allows for different qualities of investment to trend at different rates over time (or, alternatively, picks up the impact of temporary measurement error in the quantity variable which can generate a correlation between lagged prices and current quality change). The GDP growth rate and the interest rate interaction terms allow for business cycle and interest rate fluctuations to have differential impacts on quality. The equipment-to-GDP ratio allows for a scale effect on quality.

The results show that while some of these factors are significant, they do not change the estimated impact of tax policy and they appear, if anything, to go the opposite way. Quality increases with tax subsidies but not with investment generally. The scale effect is small and insignificant and during booms, investment shifts in the opposite direction—toward lower priced equipment. The coefficient on the tax term still has a significant, negative coefficient with an almost identical magnitude. There is also a trend toward higher quality over time.

Collectively, the cross-sectional results point to a quality effect of tax policy that is significant, robust, and is tied to tax policy as opposed to investment more generally. The next section of the paper develops a method of aggregation to quantify the importance of this quality shift for aggregate investment.

IV. A Theory of Aggregation

In this section I move from the product level analysis to an aggregate analysis in order to measure the magnitude of the effects. The theory extends the theoretical intuition presented above that tax policy can change relative prices and alter aggregate quality. The model follows on the work of Boorstein and Feenstra (1991) who examine the effects of import quotas on quality, but extends it to allow for more general varieties of subsidy or taxation.

It begins with an economy having a production function where one argument in the function is a capital aggregate $g(x)$ which is increasing, concave, and homogenous of degree one (x is a column vector of the quantity of M discrete varieties of capital). All other inputs in the production function are denoted z. Assuming that capital is weakly separable from the other inputs in production, the production function can be written

$$y = f[g(x), z], \tag{4}$$

where y is output. Separability implies that the cost function can be written

$$C[p(p), v, y], \tag{5}$$

where p is the column vector of prices for the M capital varieties, v is the price vector for other inputs and $p(p)$ is the unit-cost function for capital which minimizes total capital spending, $p'x$, given that $g(x) = 1$. This unit-cost function is increasing, concave, and homogeneous of degree one.

A good measure of capital quality, A, would be $g(x)/x'm$, (where m is a column vector of ones) which gives the aggregate amount of capital input divided by the number of capital units. Boorstein and Feenstra (1991) show that for the cost minimizing choice of capital varieties, x_o, (given p, v, and y) this can be expressed

$$A = \left(\frac{p' x_o}{x_o' m} \right) / p(p). \tag{6}$$

In words, quality is the weighted average price per capital good (also known as weighted average unit value or UV) divided by the unit cost function at the same price vector. Using (6), the change in log quality between any two periods can be written

$$\ln A_1 - \ln A_0 = \ln\left(\frac{UV_1}{UV_0} \right) - \ln\left(\frac{p(p_1)}{p(p_0)} \right). \tag{7}$$

Defining the periods as pre- and post-tax, this equation can be used to determine the amount of quality change induced by a tax subsidy toward investment. For a general *ad valorem* subsidy with a rate, s_i, which differs by variety (because of different intensities of future maintenance requirements, for example), let the vector p_s be the subsidy adjusted price vector. For any variety i, the entry in p_s is $p_i(1-s_i)$.

We know that the weighted unit value (average price) given a vector of prices p is

$$UV = \left(\frac{p' x}{x' m} \right) = \left(\frac{p' C_p p_p}{C_p p_p' m} \right) = \left(\frac{p_p' p}{p_p' m} \right), \tag{8}$$

and that the numerator of the last term is equal to $p(p)$ because the unit-cost function is homogeneous of degree one. Using the pre- and post-subsidy versions of (8) for the UV expressions in (7), the quality change induced by the subsidy can be written

$$\ln A_1 - \ln A_0 = \ln\left(\frac{p(p_s)}{p_p(p)'m} \Big/ \frac{p(p)}{p_p(p_s)'m} \right) - \ln\left(\frac{p(p_s)}{p(p)} \right) \qquad (9)$$

$$= \ln\big(p_p(p)'m\big) - \ln\big(p_p(p_s)'m\big). \qquad (10)$$

In general, the sign on this expression will be indeterminate. Subsidies could raise or lower quality depending on which goods get the larger subsidies. Appendix B, however, shows that if subsidy rates are highest for the high priced (i.e., high quality) goods, this is likely to lead to quality upgrading and that if the subsidy rate is constant over all goods, the quality change will be zero because relative prices do not change.

This conclusion, however, is of more than just theoretical interest. The measure of quality change between any two years as described in (7) can be directly calculated using the *CIR* data. The first term is just the change in the log of the weighted average unit values which are directly observable. The second term is the ratio of the unit cost function pre- and post-subsidy and this can be measured by an exact price index in the sense of Diewert (1976). The correct form of the index depends on the true unit cost function. If the unit cost function is Translog, the second term will be a Divisia price index (with a quadratic function the price index would be Fisher Ideal). Using the Divisia, the log difference in prices between any two periods is

$$\ln\left(\frac{p(p_1)}{p(p_0)} \right) = \sum_i \frac{(S_{i1} + S_{i0})}{2} \left(\ln\left(p_i^1\right) - \ln\left(p_i^0\right) \right), \qquad (11)$$

where S_{it} is the share at time t of asset type i as a fraction of all varieties in that year.

V. Aggregate Results

A. Basic Results

Assuming Translog and using the price index of (11) for the exact index in equation (7) yields a measure of the change in aggregate quality. In words, it measures how much prices rise but cannot be attributed to the price increase of any particular variety (meaning it had to arise from composition shifts to higher priced products). This measure is related to the literature on technological change such as Jorgenson and Griliches (1967).

In practice, I compose the price index for each year using all products available in it and the previous year as described in Appendix A.[12] The percent change in quality is then the percent change in the unit value minus the percent change in the price index. This measure of quality change is also a component of real investment. If a tax change increases real investment, this can come from an increase in the physical number of capital goods or from an increase in the quality of the capital goods. The share of total investment accounted for by quality upgrading can be directly calculated. Traditional work assumes that the investment comes from a simple expansion of the existing capital stock so the real investment will be weighted toward an increase in the amount of capital with no change to the quality. The theory here predicts that the amount of quality change should depend on changes to the tax treatment of investment (as the earlier cross-sectional results suggested) so the increase in real investment will be weighted toward quality change.

The first row of table 6 presents the results of regressing the change in log quality on the change in the relative tax term, pooled in column 1 and separately by asset class in columns 2-4. Since each observation is a composite of the micro goods and the cross-sectional variance may not be stable over time (because, for example, the number of varieties changes), I correct the standard errors for heteroskedasticity using White (1980). I include the real interest rate as a control as well as a variable for the Nixon price controls which might lead to quality shifting. Including other controls such as GDP growth and the equipment investment to GDP ratio or excluding the controls did not change the results substantially.

The results on quality show that, just as in the micro level data, tax policy significantly affects the aggregate quality of capital in the direction predicted by the theory. A 10% ITC at the mean

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[12] All the reported results use the Divisia price index but were unaffected by using the Fisher Ideal instead. Although aggregation is the only way to determine a magnitude for the quality change, it does make it more difficult to control the importance of outliers than in the cross-sectional data. To do so, I drop outlying observations at the micro level as described in Appendix A but the results did not change when I capped them instead.

corporate tax rate raises quality by 11.8%. Broken out into categories, the same change raises the quality of farming machinery 10.1%, construction machinery by 10.4% and mining machinery by 15.6%. The coefficients on the other control variables are unsurprising.

The second row then puts these numbers in context by examining how changes in the aggregate value of investment are affected by tax policy. The change in real investment is computed by subtracting the change in the log of the price index from the change in the log total value of the products. This measures what the conventional literature calls "real investment" but it includes changes in both the number of investment goods sold and the quality of those investment goods. The point estimates show that real investment does rise when investment is subsidized, though the standard errors are large. Total investment rises by about 5.2% from a 10% ITC in the pooled results of column (1). This magnitude is between those found in the conventional estimates surveyed in Chirinko (1993) and the estimates of Cummins et al. (1994).

More importantly, however, I cannot reject the hypothesis that the coefficient on quality and the coefficient on value are the same, meaning all of the increase in investment comes about from an upgrade in the quality of capital with no increase in the physical quantity of capital goods. Indeed the point estimates indicate that total value rises less than quality rises, i.e., if anything the physical number of units sold is declining at the same time the total value of investment is rising. In all three cases the point estimates imply that the physical amount of investment actually declines while the value of investment is rising.

The third row of table 6 presents results for the change in the price index calculated in (11). They show that, in addition to the quality effects, tax changes also cause true prices to rise, confirming the results of Goolsbee (1998a, 2000b) which showed that the supply of capital is upward sloping with an elasticity of about 1. Here a 10% ITC at the mean raises prices by 5.6% overall, almost exactly the same as the investment increase estimated above, also implying a supply elasticity of about 1. Separated out, the price increase is 8.5% for farming machinery, 1.6% for construction machinery, and 7.5% for mining machinery. Because of potential composition shifting within 7-digit product classes, some of this price increase may also reflect quality upgrading within product category.

Finally, the change in the average per-unit price (UV) is the sum of the quality and price effects listed in table 6. The results show that about two-thirds of the change in the average price per unit in the pooled results comes from quality upgrading and the other third from price increases. Broken out by industry, this is 1/2 for farming machinery, 2/3 for mining machinery, and 5/6 for construction machinery.

The aggregate results therefore both confirm the cross-sectional results that taxes influence capital quality and emphasize that all of the increase in real investment generated by a tax subsidy comes about from firms switching to better machines rather than buying more machines. Beyond the important macroeconomic implications of this result, the quality change is also particularly significant for analyzing the efficiency costs of investment tax policy. Holding other things equal, the change in the composition (quality) of investment is a tax induced distortion which will have an additional deadweight loss (DWL) that the conventional literature on investment has neglected; the data suggest it may be quite important.

VI. Deadweight Loss

A. Theory

The important role of tax policy on the quality of capital goods in these sectors means that the aggregate level of quality will differ from the optimum whenever the tax treatment of investment differs from full expensing (in either direction). This implies that tax policy creates an additional deadweight loss (DWL) which is forgotten in conventional studies because they use only price deflators and investment. A major advantage of the index number approach to aggregation used above is that, as shown in Boorstein and Feenstra (1991) and Feenstra (1995), it provides a convenient way of measuring the true DWL and I adapt their methods here.

Defining DWL, as in Diamond and McFadden (1974), as the revenue required to pay for the subsidy minus the reduction in production costs resulting from the subsidy, the DWL from a general *ad valorem* subsidy can be written

$$L_s = C_p \mathbf{p}_p(p_s)' S - \left(C[\mathbf{p}(p), f, y] - C[\mathbf{p}(p_s), f, y]\right), \tag{10}$$

where S is a matrix of the subsidy of each variety (the entry for good i is $s_i p_i$). The loss for a quality neutral subsidy with a constant rate across varieties, $\bar{s}$, is

$$L_{\bar{s}} = C_p p_p(p(1-\bar{s}))'\bar{s}p - \left(C\left[p(p),\, f, y\right] - C\left[p(p(1-\bar{s}),\, f, y\right]\right). \qquad (10')$$

Appendix B shows that for the neutral subsidy of (10’), there is no induced quality change so a natural way to isolate the DWL created solely by the quality shifting is to compare the DWL in (10) to the DWL from a neutral subsidy of the same size (i.e., unit cost equivalent) using equation (10’). The Appendix shows that the magnitude of this additional DWL, measured as a share of total capital expenditures after the subsidy, can be calculated as

$$W = 1/P^A(p, p_s) - 1/P^E(p, p_s), \qquad (11)$$

where P^A is a Paasche price index with the post-subsidy quantities and P^E is the exact price index. This DWL should be larger the farther the cost of capital is from pure neutrality (in either direction).

B. Measurement

On problem with the measure in (11) is that because the Paasche index understates true inflation (and thus the inverse overstates it), this measure will get worse over time due to general inflationary trends unrelated to tax policy. The measure will only be a valid approximation in the short-run so I focus only on the two years following the change to avoid the long horizon bias.

A second problem with measuring the DWL in (11) is that it must be computed relative to a base year with no quality distortion. This is hard to find. Instead I look at the DWL two years after 1964, 1975, and 1980 because each of those base years had a relative tax cost of capital within about 1-2% of complete expensing. The results are presented in table 7. The DWLs range up to about 1% of investment expenditure.

Dividing the DWL by the average change in the cost of capital for these same years implies a “coefficient” of about 0.1 indicating that a 10% ITC at the mean corporate tax rate (which lowers COC by .18) could create a DWL of around 1.8% of investment expenditure—almost 20% of the revenue spent on the subsidy. Likewise, raising the tax on capital so that the cost exceeds neutrality, such as occurred in the Tax Reform Act of 1986, will also generate a quality induced DWL.

To see how important this efficiency cost can be, compare it to the DWL one finds using estimates in the conventional literature (i.e., ignoring quality). Without quality change, the DWL of a tax (or subsidy) can be approximated by

$$DWL = \frac{1}{2} t^2 \frac{1}{\left(h_S{}^{-1} - h_D{}^{-1}\right)}. \tag{12}$$

Conventional estimates normally assume that the supply curve is perfectly elastic and estimate the elasticity of demand between 0 and -.4 (see Chirinko, 1993) implying a DWL between 0 and 0.6% of expenditure on the subsidy for the 10% ITC subsidy or equivalently sized tax. Even using the estimates in Goolsbee (1998a) which indicate a supply elasticity of approximately 1 and a demand elasticity of approximately -1.25, the DWL is only 0.9% of expenditure.

In other words, the conventionally calculated DWL from an investment tax or subsidy amounts to between 0 and 9 percent of the revenue spent on an ITC or revenue raised from a comparable tax. The quality distortion arising from the same policy, however, may generate an efficiency loss of as high as 20 percent.

The short-run character of the calculation does not take into account any externalities associated with quality change. In the long run, for example, providing better quality goods may induce more research and development which was too low before the subsidy, or it may have other externalities which make the DWL of capital subsidies smaller than these calculations suggest.[13] In such cases, however, the DWL from an equivalent investment tax increase would be even larger than indicated here because the negative externalities from quality downgrading are not captured in the calculation.

At the least, although there are caveats and the calculation is, by its nature, approximate, the imputed DWL suggests that quality change may have an important efficiency cost which has been previously neglected and should be pursued in future work.

VI. Conclusion

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[13] Romer (1994) analyzes the related issue of how taxes and tariffs might reduce welfare by slowing the introduction of new goods.

This paper puts forward the idea that tax policy can change the relative price among capital varieties and thus lead to shifts in the quality composition of investment demand. Using data on mining, construction, and agricultural machinery, the cross-sectional evidence indicates that when the cost of capital falls, the sales of higher quality (i.e., more expensive) capital varieties disproportionately increase and the reverse when it rises. This effect is not a general feature of investment but rather appears to be somewhat specific to tax policy.

The paper then establishes a means of aggregating the micro-data to shows that the overall effect of tax induced quality change is large. The entire increase in investment caused by tax subsidies comes about from an increase in the quality of the machines, not the number of machines as in the conventional literature. Prices rise, as well, supporting the idea of an upward-sloping supply curve for these products.

Finally, the paper presents calculations suggesting that the quality distortion created when tax policy differs from full expensing generates an additional deadweight loss which has been neglected in previous work and that this efficiency cost may be quite large.

Taken together, these results have important implications for evaluating the costs and benefits of investment tax policy and they suggest that the role of taxes on quality may be a fruitful area of further research.

Appendix A: Data Sources

A. The *Current Industrial Reports*

The results in the text are based on the quantity and unit value data from the *Current Industrial Reports*. Responding to the reports is mandatory for some industries and voluntary for others (details can be found in Census, 1995). As with all government data, strict disclosure rules prevent the release of data that could be used to identify individual companies.

The data in this study come from industries classified by the *CIR* as Heavy Machinery but where responses are mandatory (ruling out machine tools and truck trailers) and where the data do not suffer from serious disclosure problems (ruling out engines). This leaves three industries: Mining Machinery and Mineral Processing Equipment (MA35F), Construction Machinery (MA35D) and Farm Machinery and Lawn and Garden Equipment (MA35A). The information in Census (1995) indicates that for each of the industries that remain, the "coverage" rate (defined as the share of total shipments accounted for by the survey respondents) exceeds 95%.

Each *CIR* usually reports both the current and previous year; therefore I include for each year the products reported for both years. *CIR* products are chosen by the Census upon the request or recommendation of the respondents themselves and the included varieties do change over time. Occasionally product types are combined or split and these years often showed rather large discrete jumps in the unit value (somewhat unsurprisingly) so in the year of the change I excluded them. Including them, however, only made the results stronger. I correct for noise in the data for each of the capital types by capping the quantity change for any variety at the 5th or 95th percentile, respectively, in the cross-sectional results. This did not affect the results very strongly (as the results using median regressions would suggest). In the aggregate quality indices, I simply drop any goods whose prices more than double or get cut more than in half in a single year. This is approximately 5% of the observations. The results were basically identical capping them at these values rather than dropping them.

Some particular issues for each industry are as follows: For construction machinery, the time period with continuous data was 1961-1988. I removed tractors since they often experienced different tax treatment from other types of construction equipment in this sample. For farm equipment, there are a number of product types with very low unit values which would not, sold individually, be counted as capital goods. I restrict the sample to only those machines with a real price of more than $200 in 1987 dollars. The results were not qualitatively different varying this cutoff point, however. For farm machinery, I again excluded tractors and lawn and garden equipment which often faced different tax treatment. The consistent time period available for this industry is 1966-1988. For mining machinery and mineral processing equipment, the data are reported consistently from 1962-1988.

B. Information on Repair Costs

For information on the relationship of base prices and future repair costs for construction machinery and for mining machinery, I use the *Contractors' Equipment Cost Guide* (Primedia, 1999) released by Primedia Information's Machinery Information Division (K-III) in cooperation with the Associated General Contractors of America. The data come from surveys conducted by the AGC and the K-III Machinery Information Division of Primedia. It is a very common reference document used in the industry to predict operating expenses.

In it, for each of the several thousand types of capital equipment, the report gives, among other things, the estimated base price of the capital (the list price for a new model), estimated total hours of use in the good's lifetime, the average annual hours of use, and the estimated hourly cost of repair expenses (including preventive maintenance, overhaul, parts, supplies, tires, and lubrication). The data are classified in several levels. There are general categories of equipment such as Air Tools. Within them there are types of equipment such as Air Track Drills. Within those there are equipment types such as Ingersoll-Rand or Gardner-Denver or, in other cases diesel powered or gasoline powered, and within those a model variety such as the Ingersoll-Rand CM345/ARH.

Of the broad categories, Asphalt and Bituminous, Compaction, Concrete, Excavating, Lifting, and Road Maintenance contain varieties of capital found in the construction machinery data of the *CIR*. These data include 541 general types of construction machinery and 4449 different models. Air Tools and equipment, Crushing and Conveying equipment, and Drilling equipment, report on types of machinery similar to those found in the mining machinery data of the *CIR*. This includes 83 general types of mining machinery with 1082 different models.

To calculate the NPV of future repair costs for these types of capital, I take the average hourly repair expenses, multiply by the annual hours and calculate the NPV of expenses using a real discount rate of .05 and the effective service life of the machine (calculated by dividing the equipment's economic hours by its average annual hours). These lives ranged from 3.4 to 11.8 years for mining machinery and 3.2 to 17.5 years for construction. machinery

Agricultural machines are not included in the AGC guide so I must rely on less comprehensive information to estimate the future maintenance expenses. For them I turn to maintenance costs estimates computed from AGMACH$, a computer software program created at Oklahoma State University to estimate the costs of operating agricultural machinery (Hulke, 1999). This program analyzes the costs of 39 different types of agricultural machinery. In it, a farmer inputs a variety of information such as the size of the farm (in acres), the cost of fuel per gallon, and so on, and the program calculates projected costs. Included in these projections are estimates of the annual hours of use, the years of service, and the annual repair costs. These repair costs are not as comprehensive as those in the construction machinery data as they assume the farmer does all the work himself and thus do not include labor costs of the repairs (in the construction data, labor costs made up about 35 to 40 percent of repair costs, on average). A base purchase price for each type of equipment is listed as a default in the program but the user is allowed to change this value. I use the basic price given in the data and I assume the default farm size of 1000 acres.

To calculate the NPV of future repair costs for these types of capital, I use the annual repair costs, a real discount rate of .05 and the service life of the machine as given by AGMACH$.

Appendix B:

Deriving the Quality Change and Deadweight Loss from a General *Ad Valorem* Subsidy

A. Quality Change

With a general *ad valorem* subsidy whose rate is greater for more expensive products, quality upgrading is not certain but is likely. Before showing this, first note the quality change induced in two special cases as proven in Boorstein and Feenstra (1991). First, for a subsidy with a constant rate, s, for all capital varieties, equation (10) in the text becomes

$$\ln A_1 - \ln A_0 = \ln\left(p_p(p)'m\right) - \ln\left(p_p(p(1-s))'m\right) \tag{A}$$

and since the function $p_p(\cdot)$ is homogenous of degree zero, $p_p(p) = p_p(p(1-s))$ and the quality change is exactly zero. This is not surprising since the constant rate subsidy does not change relative prices so it induces no shifting.

The other special case is where the subsidy is a constant dollar amount of s per unit so that the entry for any variety in the p_s vector is $p_i - s$. Under very general conditions, they show that this led to a quality downgrade. Again this is intuitive since if there is a per unit subsidy, a firm will try to buy as many small units as possible.

In this paper I consider the more general subsidy which alters the price vector to p_s where the entry for each asset is $p_i(1-s_i)$. The subsidy induced quality change is

$$\ln A_1 - \ln A_0 = \ln\left(p_p(p)'m\right) - \ln\left(p_p(p_s)'m\right), \tag{B}$$

and, by monotonicity, this will have the same sign as

$$\left(p_p(p)'m\right) - \left(p_p(p_s)'m\right). \tag{C}$$

Defining $\Psi(l) = p_p\left[lp + (1-l)p_s\right]'m$, this can be re-written

$$\left(p_p(p)'m\right) - \left(p_p(p_s)'m\right) = \Psi(1) - \Psi(0). \tag{D}$$

The mean value theorem tells us that for some $l_0 \in [0,1]$,

$$\frac{\Psi(1) - \Psi(0)}{1-0} = \Psi'(l_0). \tag{E}$$

Evaluating this derivative using the definition of $\Psi(l)$ yields

$$\Psi'(l_0) = S'p_{pp}\left[l_0 p + l_0 p_s\right]m \tag{F}$$

where S is a column vector whose value for any capital variety is $s_i p_i$ and p_{pp} is the Hessian of the unit-cost function. Because the cost function is concave the Hessian is negative semi-definite. Writing out the derivative in (F),

$$\Psi'(l_0) = \sum_{i=1}^{M} s_i p_i \sum_{j=1}^{M} p_{ij}, \tag{G}$$

where $p_{ij} = \P^2 p \big/ \P p_i \P p_i$. In general, this equation is of indeterminate sign but it is possible, as one might expect, to show that quality rises so long as the “correct” varieties get the higher rates of subsidy.

Since a constant dollar subsidy across goods reduces quality, (F) must be negative if the $s_i p_i$ for each asset is replaced by a constant s. Dividing (F) by s in that case implies that

$$\sum_{i=1}^{M} \Pi_i < 0 \ , \tag{H}$$

where $\Pi_i = \sum_{j=1}^{M} p_{ij}$.

Likewise, an *ad valorem* subsidy with a constant rate, s, for all varieties induces no quality change so equation (G) must be zero in this case. Dividing (G) by s implies that

$$\sum_{i=1}^{M} p_i \Pi_i = 0. \tag{I}$$

Taken together, (H) and (I) show that while the sum of the Π_i terms is negative, when weighted by price, the sum is zero. Since all the prices are greater than zero, the prices and the Π_i terms must be correlated, meaning prices are larger for the larger (e.g. positive) Π_i terms.

Returning to the general formulation of (G), equation (I) implies that subtracting $\sum_{i=1}^{M} s p_i \Pi_i$ should have no effect if s is constant over all varieties since the sum is zero. Choosing s equal to the average subsidy rate across varieties yields a simple sufficient condition for non-neutral subsidies to increase aggregate quality. Splitting the new (G) condition into positive and negative terms, there will be quality upgrading from a subsidy whenever

$$\sum_{i=1}^{M_0} (s_i - s) p_i \Pi_i + \sum_{j=1}^{M_1} (s_j - s) p_j \Pi_j > 0 \tag{J}$$

where the M_0 varieties have $\Pi_i > 0$ and the M_1 varieties have $\Pi_j < 0$.

A simple guarantee that this is true is for the subsidies to be greater than average for the M_0 varieties and lower than average for the M_1 varieties. Since the Π_i terms are just the sum of the second derivatives of the unit cost function, this condition says, in a sense, that we can be sure that general *ad valorem* subsidies raise quality if the rates are highest for the goods that are less cross-price responsive. In that sense it is similar to the cross-price elasticity conditions in Borderching and Silberberg (1978) for the Alchian-Allen theorem to hold in the presence of more than two goods. This condition is also intuitively plausible since (H) and (I) imply that the higher priced varieties already have the largest Π_i terms, on average, and I have argued that the implicit subsidy rates on capital are highest for the higher quality goods.

B. Deadweight Loss

To isolate the DWL generated by the quality change induced by tax policy, consider a subsidy of the same size as the one with rates that vary by quality but with a constant rate $\bar{s}$ across capital varieties following the method of Boorstein and Feenstra (1991). By same size I mean that the subsidy makes firms indifferent between the general and the neutral subsidy in terms of the unit cost function:

$$p(p_s) = p(p(1-\bar{s})). \tag{A'}$$

Since $p(p)$ is homogenous of degree one, this also implies that

$$p_p(p_s)'S = p_p(p(1-\bar{s}))'p(1-\bar{s}). \tag{B'}$$

Using (A') and canceling terms, the difference between the DWL of the two subsidies (given by equations 10 and 10' in the text) can be written

$$L_s - L_{\bar{s}} = C_p p_p(p_s)'S - C_p p_p(p(1-\bar{s}))'\bar{s}p. \tag{C'}$$

Solving (B') for $C_p p_p(p(1-\bar{s}))'\bar{s}p$, noting that $p(p)'p = p(p)$ and that $p_p(p(1-\bar{s})) = p_p(p)$ by homogeneity, and then plugging into (C') yields

$$L_s - L_{\bar{s}} = C_p p_p(p(1-\bar{s}))'p - C_p p_p(p_s)'p = C_p(p(p) - p_p(p_s)'p). \tag{D'}$$

To express this measure of the DWL from quality change in a form that can be calculated but is also intuitive, note that the total expenditure on capital after a general subsidy is $C_p p_p(p_s)'p_s = C_p p(p_s)$. The DWL as a fraction of this investment expenditure is thus

$$W = \left(\frac{L_S - L_{\bar{S}}}{C_p p(p_s)}\right) = \frac{p_p(p_s)'p}{p_p(p_s)'p_s} - \frac{p(p)}{p(p_s)}. \tag{E'}$$

Basic index number theory, however, defines the Paasche index of the price change caused by the subsidy, $P^A(p, p_s)$ to be

$$P^A(p, p_s) = \frac{C_p p_p(p_s)' p_s}{C_p p_p(p_s)' p} = \frac{p_p(p_s)' p_s}{p_p(p_s)' p},$$

and the exact price index between the periods as

$$P^E(p, p_s) = \frac{p(p_s)}{p(p)}. \tag{G'}$$

The additional DWL caused solely from the quality change, as written in (E'), can be calculated as

$$W = \frac{1}{P^A(p, p_s)} - \frac{1}{P^E(p, p_s)}, \tag{H'}$$

the difference between the inverse of a Paasche price index and the inverse of the exact price index. This statistic is easily calculated with the *CIR* data.

TABLE 1:

PRICE DISTRIBUTION OVER FULL SAMPLE BY ASSET CLASS (IN 1987 DOLLARS)

	Farming Machinery	Construction Machinery	Mining Machinery
10th Percentile	461	6,636	10,774
25th Percentile	876	18,166	22,196
Median	1,973	67,076	51,987
75th Percentile	4,263	174,659	119,968
90th Percentile	8,780	394,967	243,573
Mean	4,173	202,657	96,751
Std. Dev.	7,237	658,652	121,549
Number Obs.	3101	1680	907

Notes: Author’s calculations using *Current Industrial Reports* as described in the text.

TABLE 2:
QUALITY CHANGE EXAMPLE FOR A SUBSET OF MINING EQUIPMENT

SIC Code	Product	Price 1980	✆q/q 1980-81	Share of total value 1980	Share of total value 1981
3532575	Mine cars	9.4	-.34	.033	.022
3523577	Rock dusters	15.0	.04	.013	.011
3532576	Support vehicles, rubber tired or track-mounted, towed	23.7	-.50	.025	.013
3532572	Support vehicles, rubber tired or track-mounted, self-propelled	29.5	.11	.027	.026
3532537	Loader machines: scoops, shovels and buckets	60.4	-.37	.161	.084
3532558	Ratio feeders and feeder breakers	65.9	.04	.063	.062
3532535	Loader-hauler-dumper underground mine loader machines	83.8	.31	.096	.118
3532557	Face-haulage vehicles, rubber tired, self-propelled	100.0	.30	.137	.175
3532543	Continuous mining machines, borer, ripper, auger, and drum	387.3	.15	.446	.488

Source: Calculated from *Mining Machinery and Mineral Processing Equipment, 1981*.

TABLE 3: FUTURE REPAIR COSTS AS A FUNCTION OF BASE PRICE

	(1) Farming	(2) Construction	(3) Mining
<u>All Models</u>			
Ln (Base Price)	--	.6970	.6625
		(.0047)	(.0054)
Equip. type dummies	--	Yes (541 types)	Yes (83 types)
N	--	4449	1082
R^2	--	.993	.998
<u>One Model per Type</u>			
Ln (Base Price)	.7960	.7317	.7580
	(.0686)	(.0176)	(.0216)
Constant	-1.3602	1.5052	1.7617
	(.1751)	(.0735)	(.0957)
Equip. type dummies	No	No	No
N	39	541	83
R^2	.785	.762	.938

Notes: The dependent variable in each regression is the log of the NOV of future maintenance expenses for the capital good as described in the text. Standard errors are in parenthesis. Column (1) using data from AGMACH$. Columns (2) and (3) use repair data from the *Construction Equipment Cost Guide*.

TABLE 4:
CHANGE IN OUTPUT AS A FUNCTION OF INITIAL QUALITY BY INDUSTRY

Dep Var: $\Delta q / q$	**Farming Machinery**	n R^2	**Construction Machinery**	n R^2	**Mining Machinery**	n R^2
Weighted OLS						
1981	.0271	126	.0375	83	.0898	54
	(.0153)	.025	(.0181)	.051	(.0279)	.166
1986	-.0605	125	-.0557	65	-.0149	50
	(.0197)	.071	(.0202)	.108	(.0293)	.005
Median Reg.						
1981	.0466	142	.0469	83	.0696	54
	(.0281)	--	(.0265)	--	(.0292)	--
1986	-.0642	140	-.0433	65	-.0648	50
	(.0246)	--	(.0223)	--	(.0369)	--
Pooled: All Yrs (w/yr dums)						
Weighted OLS	-.2224	3101	-.2965	1680	-.1672	907
	(.0751)	.191	(.0869)	.179	(.1361)	.218
Median Reg.	-.1947	3101	-.1752	1680	-.2516	907
	(.0421)	---	(.0261)	---	(.0435)	---

Notes: The dependent variable in each regression is the percent change in quantity for the year measured in physical units. The coefficient for the first four rows is for the log of the lagged price of the variety. For the last two rows, the coefficient is for the log of the lagged real price of the good interacted with the change in the tax cost of capital for the year. The constant terms for the first four rows and the coefficients on the year dummies for the last two rows are not reported for simplicity. The regressions are restricted to the individual industry listed at the top of the column.

TABLE 5:
CHANGE IN OUTPUT AS A FUNCTION OF INITIAL QUALITY: POOLED

Dep Var: $\Delta q / q$	(1) ΔCOC_t<<0	(2) ΔCOC_t>>0	(3) Small ΔCOC_t	(4)	(5)
$Ln(P_{t-1})$	.0222 (.0087)	-.0296 (.0098)	-.0087 (.0032)		
$Ln(P_{t-1})*DCOC$				-.2303 (.0528)	-.2041 (.0535)
$Ln(P_{t-1})*r$					-.4681 (.1512)
$Ln(P_{t-1})*GDP\%$					-.3940 (.1169)
$Ln(P_{t-1})*EQ/GDP$					.0422 (.1409)
$Ln(P_{t-1})$					.0279 (.0221)
Industry-Yr Dums	No	No	No	Yes	Yes
Industry Dums	Yes	Yes	Yes	---	---
n	602	464	4622	5688	5688
R^2	.036	.050	.011	.184	.190

Notes: These regressions pooling the cross-sectional data from table 2 for all three asset types and restrict the coefficients to be the same as described in the text. Standard errors are in parentheses. $Ln(P_{t-1})$ is the log of the real price at the start of the period. Column 1 includes only years where the tax cost of capital falls by more than .05. Column 2 includes only years where it rises more than .05. Column 3 is for tax changes smaller than .05 in absolute value. Columns 4 and 5 include all years. *EQ/GDP* is the ratio of equipment investment to GDP in the year, $GDP\%$ the GDP growth rate, r the real baa bond rate, and ΔCOC_t the change in the relative tax term.

TABLE 6:
AGGREGATE RESULTS

	(1) Pooled	(2) Farm	(3) Constr.	(4) Mining
Dep Variable: DQuality				
ΔCOC_t	-.6628	-.5620	-.5805	-.8697
	(.1998)	(.2056)	(.3845)	(.4518)
Interest Rate	-1.1211	-.9811	-1.0310	-1.3444
	(.4376)	(.4329)	(.5201)	(1.1637)
Price Controls	-.1246	-.0819	-.1564	-.1363
	(.0653)	(.0432)	(.1796)	(.0533)
n	77	23	28	26
R^2	.29	.46	.27	.07
Dep Variable: DReal I				
ΔCOC_t	-.2872	-.4467	.0888	-.6485
	(.2160)	(.3735)	(.3491)	(.4780)
Interest Rate	-2.3662	-2.7800	-1.6745	-2.6492
	(.8648)	(1.2944)	(1.5972)	(1.6571)
Price Controls	-.0401	.0112	.0839	-.2265
	(.0710)	(.0943)	(.0968)	(.0664)
n	77	23	28	26
R^2	.25	.31	.10	.33
Dep Variable: DPrice				
ΔCOC_t	-.3064	-.4765	-.0949	-.4142
	(.1174)	(.1861)	(.1923)	(.1757)
Interest Rate	-.4940	-.4091	-.7144	-.3478
	(.1968)	(.2946)	(.3405)	(.3938)
Price Controls	-.0738	-.1113	-.0619	-.0548
	(.0261)	(.0423)	(.0471)	(.0438)
n	77	23	28	26
R^2	.28	.46	.25	.25

Notes: The dependent variable is listed at the top of the first column of each panel. The variables in question refer to the aggregate measures as described in the text. For each panel, the individual columns present regressions for the industry listed at the top. The constant terms (or inustry dummies in the case of column 1) are not reported. The interest rate is the real baa bond rate. The price control variable represents the Nixon price controls and ΔCOC_t is the change in the relative tax cost of capital for the asset. Standard errors are in parentheses and are heteroskedasticity corrected as in White (1980).

TABLE 7:
DWL FROM QUALITY CHANGE FOR SELECTED YEARS

Year	Farming COC	Farming DWL	Construct. COC	Construct. DWL	Mining COC	Mining DWL
1980	1.009		1.008		1.001	
1982	.938	0.7	.938	0.3	.938	1.0
1975	1.017		1.019		1.013	
1977	.965	0.5	.964	0.4	.961	1.0
1964	--	--	1.011		1.009	
1966	--	--	1.054	0.3	1.045	0.8

Notes: Calculated as described in the text. COC is the tax cost of capital. The DWL is measured in percentage terms as a share of investment expenditure.

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