# The Yield Curve as a Determinant of Investment in Durable Capital

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**Abstract**

I study and test for a relationship between the shape of the yield curve and the composition of firms' capital structure with respect to durability. This empirical test takes the form of a dynamic panel model, estimated using firm level financial data and US government bond yields. The results indicate that a decrease in the cost of long-term debt leads firms to shift to higher durability capital and vice-versa, supporting the claim that firms internalize the heterogeneous required financial market returns (or opportunity costs) of capital inputs with different expected service lives.

**Keywords:** Durability; Depreciation; Yield Curve; Cost-of-Capital

**JEL codes** D21, D22, D92, G12

# 1. Introduction

The empirical analysis conducted below examines the composition of capital investment for publicly held companies using data from the Compustat database.[1] In this context "composition" refers to the relative quantities of each of a set of heterogeneous capital inputs, differentiated based on durability. In this paper I develop and empirically test the hypothesis that changes in the average durability of a firm's capital stock are affected by changes in the term premiums associated with long and short term debt.

The determinants of capital durability are important and constitute a relatively unexplored component of the broader exercise of understanding capital investment patterns generally. Capital durability choices affect a firm's depreciation rate and potentially, by extension, its cost of capital. Significant efforts in the fields of economics and finance have been devoted to analyzing the determinants of aggregate investment with much of the extant literature focusing on taxation and financing issues.[2] However, the standard approach in economics and finance literature largely ignores the durability issues by assuming a single, fixed (with respect to capital durability) cost of capital and a single homogeneous capital stock.

Identifying the existence of a relationship between the shape of the yield curve and the durability of a firm's capital asset investments has implications for monetary policy tools, specifically open market operations. Recent work indicates that changes in the maturity of treasury debt and changes in the total supply of public debt can and do influence the term structure of interest rates.[3] The objectives of open market operations are tied to macroeconomic indicators (inflation rates; exchange rates and balance of payments) and the causal channel through which open market operations effect these indicators inevitably involves capital investment.

An early example of the use of open market operations to change the shape of the yield curve, and by extension affect both private investment and the balance of payments came in the form of Operation Twist-1961 (see Modigliani and Sutch 1966). A second Operation Twist-2011

[1] Compustat (North America) 2/28/2014. www.compustat.com/

[2] See for example: Jorgenson and Siebert (1968), Jorgenson (1972), McKenzie et. al. (1997) and Baker et. al. (2003)

[3] Gagnon et. al. (2010); Greenwood and Vayanos (2010); Kuttner (2006); Engen and Hubbard (2005); Gale and Orszag (2004); Bernanke et. al. (2004)

was enacted in the wake of the global financial crisis along with three rounds of "quantitative easing" between 2008 and 2012. Each of these major exercises as well as the myriad other open market operations conducted by monetary authorities have effected the level of interest rates and the relationship between long and short term rates with consequences for not only the magnitude but also the composition of capital investment. While current research has done much to examine the magnitude of investment resulting from changes in the opportunity cost of capital (through estimation of elasticities of investment and the like) the potential for yield curve variations to affect the composition of this investment has been all but ignored.

The analysis here shows that changes in the shape of the yield curve affect the durability of capital investment. This implies that monetary policy can be used to stimulate specific kinds of physical capital acquisition insofar as durability is concerned. I remain agnostic regarding the desirability of this policy tool, but even if the ability to affect capital investment durability is not a priority for monetary authorities, the existence of the effects identified here imply an unintended consequence of the use of open market operations. It is evident that these effects require attention in the finance and economics literature.

Dew-Becker (2012) analyzes the relationship between the term spread of interest rates and the average duration of investment across industries examining changes in corporate bond durations resulting from variations in the yield curve. He identifies a relationship similar to the one I test for here, finding evidence of an inverse relationship between the relative yield on long vs short term debt and the average duration of bond purchases. Dew-Becker identifies this yield curve / investment duration relationship using industry-level investment data. My approach is similar but not identical. Dew-Becker focuses on the duration of the bond (used to finance physical capital purchases) whereas I examine the duration of the physical assets purchased by firms.

Another approach to examining the relationship between investment decisions and the shape of the yield curve comes in the form of a production based asset pricing theory. Jermann (2013) presents such a model, under which the term structure of interest rates is driven by stochastic shocks to the production function of a representative firm.

My analysis more closely resembles Dew-Becker's approach in that no theory is presented here to explain the shape of the yield curve. I model firms as price takers in the capital markets, with the yield curve given exogenously. The difference in assumptions reflect the different goals of this paper compared to Jermann (2013). Here, the aim is to understand how variations in the yield curve affect investment patterns whereas Jermann examines how stochastic elements in revenue motivate the shape and variance of observed bond yields.

Dew-Becker (2012) examines changes in issued bond duration while Jermann (2013) models two types of assets (equipment and structures) available to the firm. I take a similar but distinct approach and define the durability of a capital investment based on the asset's inherent depreciation rate, assets with high depreciation rates have low durability and vice-versa. In the empirical section, this depreciation rate is determined via the Generally Accepted Accounting principles (GAAP).[4] Under GAAP, standard capital investment classes include 'Office Equipment', 'Vehicles' and 'Heavy Work Equipment' each with an associated depreciation period. (For example computers are depreciated much faster than heavy machinery). Since the standard yield curve on bonds indicates that longer principal repayment schedules are generally associated with higher rates of return, it is reasonable to assume that capital inputs with longer service lives (and longer associated repayment schedules) carry a proportionally higher capital cost. This assumption essentially forms the hypothesis being tested here.

The standard convention in economics and finance is to refer to a single cost of capital (generally taken as a debt/equity weighted average) applied to the entire capital stock. This obfuscates the potential effect of asset durability on the firm's cost of capital. If each capital asset carries a distinct rental rate related to its durability (i.e. its associated investment duration) then the average durability of the capital stock will affect the average cost of capital. Applying a single exogenous cost of capital (or at least a single cost of capital unrelated to asset durability) ignores even the potential for a relationship between the firm's cost of capital and its input decisions.

A common assertion in microeconomic theory is that a firm's capital input decisions are

[4]While the "generally accepted accounting principles" can differ based on industry and geographical jurisdiction, the elements pertaining to depreciation methodologies follow a generally uniform structure. In the United States, one recognized authoritative source for GAAP is the "Federal Accounting Standards Advisory Board Handbook of Accounting Standards and Other Pronouncements." This document can be found on-line at: http://www.fasab.gov/pdffiles/2013_fasab_handbook.pdf (last accessed May 2014)

based on shadow prices rather than incurred rental rates. (See, for example, Buranabunyut and Peoples 2012, p.186). Following this argument allows for an abstraction from the firm's financing decisions in assuming that the firm will internalize the *required* financial market return as a shadow cost of holding any specific capital input. The return, or price, actually paid to the firm's equity or debt holders is irrelevant. This assertion follows from the well known "Invariance Proposition" (Modigliani and Miller 1961). In broad terms, I appeal to the "Invariance Proposition" insofar as capital *financing* decisions are concerned. This appeal is based on the assertion that financing decisions do not change the underlying opportunity cost of capital or the revenue stream associated with a given set of capital inputs.

If the assertion that firms internalize the required financial market return is correct then changing the average durability of the firm's capital inputs will affect the present value of the firm's future profit stream. This effect is a result of any productivity implications and changes to the principal repayment schedule of the capital stock. Regardless of the duration of actual bonds issued by the firm and its choice of debt/equity ratio the causal channel will continue to operate.

This assertion does not invalidate the literature focused on debt/equity and bond-duration decisions. Rather it simply divorces the issue of physical asset duration decisions from the issue of financing decisions. There is still a substantial role for debt/equity and bond duration choices based on risk allocation between investors and firm agents. One leading theory here is the "maturity matching hypothesis" which posits that firms match the duration of their issued bonds with the expected economic life of their physical assets. While empirical support of this hypothesis is presented by Stohs and Mauer (1996), assuming that the firm can divorce physical asset duration decisions from financing decisions allows the analysis here to remain agnostic on the subject of maturity matching.

A further discussion of how bond durations choices can be thought of as a risk allocation mechanism can aid the understanding of the relationship between bond yields and asset duration. I turn to such a discussion presently.

## 2. The bond duration decision as a risk allocation mechanism

The yield curve on corporate or government bonds generally displays an increasing concave relationship, with longer term bonds carrying higher associated yields. Conventional economics and finance models explain this positive correlation between duration and yield as a combination of inflation and interest rate expectations and an added "term premium" for longer term bonds. In the extant literature, the term premium is generally thought of as compensation for taking on the risk inherent in longer term investment. Since the nominal return on a long-term bond is uncertain, investors are assumed to require a term premium as compensation for taking on this added risk (as compared with simply rolling over investments in short term bonds). Given the increased risk for every year until a bond's maturity this risk increases with the duration of the bond, as does the required term premium compensation.

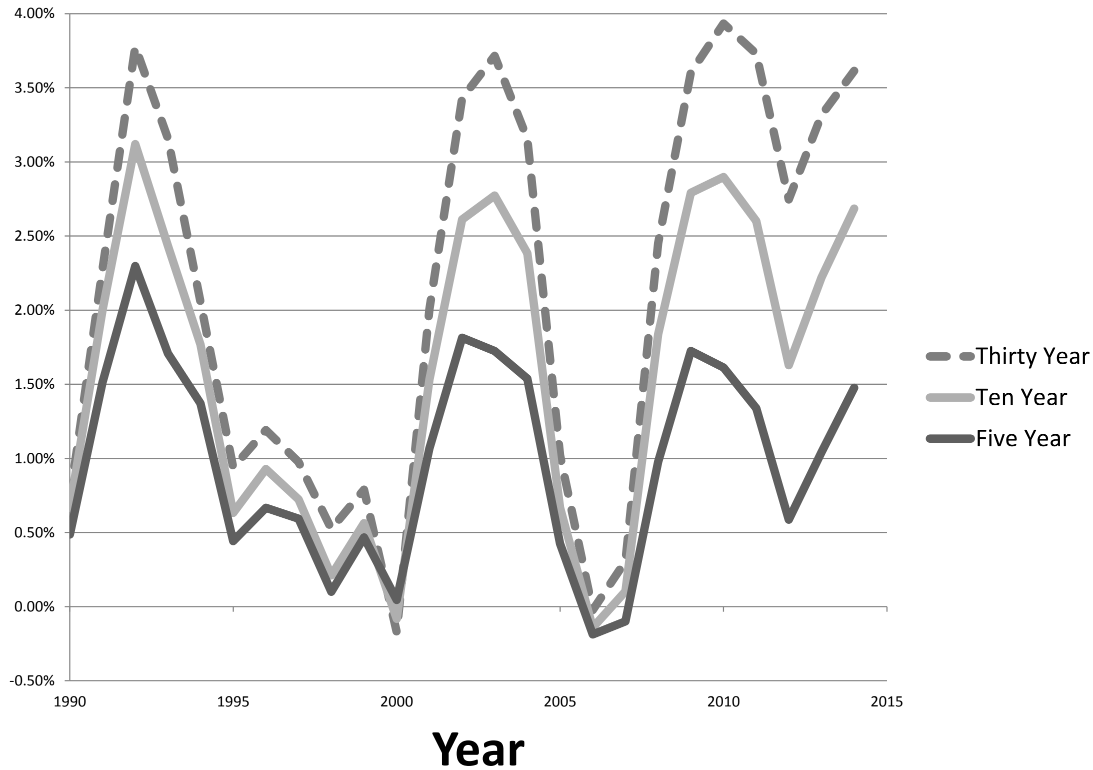
Figure 1 illustrates the average term-premiums for three durations of US government bonds over the period 1990-2014. From Figure 1 it is evident that there is significant variation in the term premiums through time. The figure indicates a steep yield curve in years 1992, 2003 and 2009 (term premiums are high and far apart), and a flat yield curve in years 2000, 2006 and 2012 (term premiums are low and close together).

Common definitions of term premium are generally mechanical in nature describing the process of calculating a term premium, rather than the underlying concept.[5] Borrowing language from expected utility literature, the term premium can essentially be defined as a "certainty equivalent" – the amount that must be paid to the investor to make him or her indifferent between taking the low-risk investment (continually rolling over short-term bonds) and the high-risk investment (purchasing the long-term bond).

Under this interpretation, the firm's residual claimant can allocate risk between herself and the debt-holders by choosing the duration of the bond. Full maturity matching (which imlies the bond duration is equal to the economic life of the firm's capital) allocates all of the inflation and interest rate uncertainty to the bond holders, which they accept in return for a high term

[5]See Kim and Orphanides (2007) for a more complete description of the term premium and its common definitions.

Figure 1: Simple Term premiums (US government Bonds 1990-2014)




The Simple Term premiums are calculated by subtracting the one-year bond yield from longer term (five, ten and 30 year) bond yields.

premium. A shorter bond yield reduces (or eliminates) the costly term premium, but shifts the risk back to the residual claimant.

Thus the term premium, acting as a certainty equivalent, represents the additional opportunity cost of holding long lived capital regardless of how it is financed. Whether or not the risk is actually shifted to bond holders is irrelevant. The inflation and interest rate uncertainty exists, and must be incurred either by the residual claimant or the firm's bond holders.[6]

In the next section I present a dynamic profit maximization model incorporating heterogeneous capital with distinct depreciation rates and additive term premiums. The equilibrium conditions for the model predict a negative relationship between investment in a specific capital

[6]The comparison is similar to the rent or own example common in most if not all undergraduate microeconomics textbooks. ie- If the firm rents its capital it pays an explicit cost, however; if the firm purchases capital, it still incurs an equivalent opportunity cost to use its own capital.

durability class and the term premium on debt with a matching maturity.

## 3. A Simple Model

Depreciation is an inter-temporal concept, and so the firm's maximization program is modeled here with a time dimension (specifically, using a continuous-time "Hamiltonian" formulation).[7] In this simple model the firm employs a set of capital inputs ($k_i$) where $i \in N$ is an index of the degree of durability and associated economic life. The production function is denoted as $Q(K)$ where $K$ is the full set of capital inputs. Production is assumed to exhibit strictly positive but diminishing marginal product for each capital input $\left(\frac{\partial Q}{\partial k_i} > 0 \;,\; \frac{\partial^2 Q}{\partial k_i^2} < 0 \quad \forall i \in N\right)$ and a non-negative degree of substitutability between assets of different durabilities $\left(\frac{\partial^2 Q}{\partial k_i \partial k_j} \geq 0 \; \forall i \neq j\right)$. Total revenue ($R$) is assumed to be a continuous differentiable function of output ($R(Q)$).

The model employs a very simple definition of the term premium as the difference between a specific term bond yield (eg. five or ten years) and the one-year bond yield. The standard one-year bond yield will be denoted as $r_f$ and treated as a base cost of capital. The term premium for a bond of duration $i$ is denoted as $r_i$ and is treated as an additional cost of capital (above the base cost of capital) for a capital asset with a duration given by $i$. The total opportunity cost of capital for each capital input $i \in N$ is then the sum of i) the asset-specific term premium ($r_i$) ; ii) the asset-specific depreciation expense ($\delta_i$); and iii) the standard single period base cost of capital($r_f$).[8]

Substituting the production function into the total revenue function and subtracting the

[7] The dynamic formulation here is primarily cosmetic. A static formulation leads to equivalent equilibrium conditions. See footnote 10.

[8] The standard convention in economics and finance is to refer to a single average cost of capital. To reconcile the above model with this convention consider that the total capital cost can be given as: $Capital\ Cost = r_a \cdot (K_{H,t} + K_{L,t})$ where the new variable $r_a$ is the commonly referenced weighted average cost of capital and takes the form $r_a = \sum_{i \in N} [(r_i + r_f) \cdot k_{i,t}] / \sum_{i \in N} (k_{i,t})$. The per unit change in total capital cost for a change in investment in an asset with a specific durability indicated $k_j$ can then be calculated as the sum of a conventional direct (marginal) effect equal to $r_a$ and a heretofore generally unrecognized indirect (infra-marginal) effect equal to $(r_i + r_f - r_a)$:

$$\frac{d\,[Capital\ Cost]}{dk_{j,t}} = r_a + \frac{\partial r_a}{\partial k_{j,t}} \cdot \sum_{i \in N} (k_{i,t}) = r_a + (r_i + r_f - r_a) = r_i + r_f$$

total opportunity cost of capital, the firm's profits in any period can be given as:[9]

$$\pi = R\left(Q\left(K\right)\right) - \sum_{i \in N} \left[\left(r_i + r_f + \delta_i\right) \cdot k_{i,t}\right] \tag{1}$$

Construction of the dynamic model requires equations of motion for each capital input. The equations of motion are specified here in continuous time:

$$\dot{k}_{i,t} = I_{i,t} - \delta_i \cdot k_{i,t} \ \ \forall i \in N \tag{2}$$

where $I_{i,t}$ are units of new capital investment in class $i$ by the firm. (A dot above a variable indicates a time derivative.) The firm's problem is then to maximize equation (1) subject to equations (2). The current value Hamiltonian representing this maximization program (in continuous time) is:

$$H = R\left(Q\left(K\right)\right) - \sum_{i \in N} \left[\left(r_i + r_f + \delta_i\right) \cdot k_{i,t}\right] + \sum_{i \in N} q_{i,t}\left(I_{i,t} - \delta_i \cdot K_{i,t}\right) \tag{3}$$

where $q_{i,t}$ are the costate variables for capital inputs $i \in N$.

The corresponding first order conditions are:

$$q_{i,t} = 0 \ \forall i \in N \tag{4}$$

which require that the co-state variables representing shadow values on capital inputs are equal to zero. The interpretation is that equilibrium investment exhausts any marginal net benefit of capital in the future income stream.

Imposing a steady state condition (i.e: $\dot{q}_i = 0 \ \forall i \in N$) the maximum principle conditions

[9] While the distinction is not critically important in this discussion, if the firm owns the capital assets, then equation (1) would more accurately be interpreted as a flow of "firm value" rather than profits, whereas if the firm is renting all capital the equation implies that the owner requires a debt service payment ($r_i$) as well as compensation for lost value on the asset ($\delta_i$).

can be written as:

$$\left(\frac{\partial R}{\partial Q}\right) \cdot \left(\frac{\partial Q}{\partial k_i}\right) - (r_i + r_f + \delta_{i,t}) = (r_{f,t} + \delta_i) \cdot q_{i,t} \ \ \forall i \in N \tag{5}$$

Combining equations (4) and (5) gives the following set of first order conditions:[10]

$$\left(\frac{\partial Q}{\partial k_i}\right) = \frac{(r_i + \delta_i)}{\left(\frac{\partial R}{\partial Q}\right)} \ \ \forall i \in N \tag{6}$$

From equation (6), the partial derivative for the own price effect of a change in $r_i$ is:

$$\frac{\partial k_i}{\partial r_i} = \left(\frac{\partial R}{\partial Q}\frac{\partial^2 Q}{\partial k_i^2}\right)^{-1} < 0 \ \ \forall i \in N \tag{7}$$

which indicates that the desired stock of capital in class $i$ is inversely related to the term premium $r_i$.

Again from equation (6), the cross-price effect of a change in $r_i$ is:

$$\frac{\partial k_j}{\partial r_i} = -\left(\frac{\partial^2 Q}{\partial k_i \partial k_j}\right)\left(\frac{\partial^2 Q}{\partial k_j^2}\right)^{-1}\left(\frac{\partial R}{\partial Q}\frac{\partial^2 Q}{\partial k_i^2}\right)^{-1} \leq 0 \ \ \forall i \in N \tag{8}$$

Taken together, equations (7) and (8) indicate that an increase in any specific asset term premiums (any $r_i$) will have a negative effect on the the desired stock of capital with durability $i$ and a negative or null effect on the the desired stock of all other capital with durability $j \neq i$. These implications are not surprising but serve to give some structure to the discussion above. To draw a conclusion from this exercise, empirical validation of the relationship is required. In the following section I develop an estimation equation with the express purpose of generating coefficient estimates to test the validity of the modeled relationship.

[10] This equilibrium condition is consistent with a static formulation absent a time dimension. Ignoring the investment and depreciation dynamics and directly maximizing equation (1) with respect to each capital input $k_i$ produces a first order condition equivalent to the dynamic equilibrium condition given by equation (6).

# 4. Estimation Equation

The Compustat database includes the aggregate value of the firm's capital stock as well as the firm's annual depreciation expense. While this data does not present enough information to examine the total composition of the firm's capital stock it does allow for a summary measure of the average durability of a firm's assets. Abstracting to the simplest possible definition of capital composition, wherein capital is either high or low durability (such that $N \equiv \{H, L\}$), a firm's composite depreciation rate can be defined as:

$$\delta_c = \frac{\delta_L k_L + \delta_H k_H}{k_L + k_H} \tag{9}$$

Restating the identity for composite depreciation in terms of the proportion of low and high durability capital it becomes:

$$\delta_c = \frac{\delta_L k_L + \delta_H k_H}{k_L + k_H} = \delta_L \alpha + \delta_H (1 - \alpha) = \delta_H + (\delta_L - \delta_H)\,\alpha \tag{10}$$

where $\alpha$ is the proportion of low durability capital and $(1 - \alpha)$ the proportion of high durability capital.

With only two inputs the own-price effect (of a change in $r_i$ on $k_i$) given by equation (7) is larger than the cross-price effect (of a change in $r_i$ on $k_j$) given by equation (8). That is, $\left|\frac{\partial k_i}{\partial r_i}\right| > \left|\frac{\partial k_j}{\partial r_i}\right|$ which implies that as the term premium on high durability capital ($r_H$) increases the firm will shift towards low durability capital (all else being equal) and vice versa. The proof of this relationship is omitted, but directly follows from the assumption that $\frac{\partial^2 Q}{\partial k_i^2} < 0$ and $\frac{\partial^2 Q}{\partial k_i \partial k_j} \geq 0$.

Given the direction of this relationship, $\alpha$ can be approximated by the linear equation: $\alpha = \alpha_0 + \alpha_L r_L + \alpha_H r_H$, where we expect $\alpha_L < 0$ and $\alpha_H > 0$.[11] Using this approximation,

[11] See appendix A for a discussion of issues related to the potential nonlinearity of the relationship between $\alpha$ and the term premiums measures $r_L$ and $r_H$.

equation (10) is re-written as:

$$\delta_c = (\delta_H + \alpha_0) + (\delta_L - \delta_H)\,\alpha_L r_L + (\delta_L - \delta_H)\,\alpha_H r_H \tag{11}$$

Equation (11) establishes a testable hypothesis regarding the relationship between the relative costs of low ($r_L$) and high ($r_H$) durability capital and an observable indicator of the average durability of a firm's capital inputs ($\delta_c$). If the theory outlined above is correct, econometric estimates of the parameters $\alpha_L$ and $\alpha_H$ should be signed as negative and positive respectively.

The base linear estimation equation used in the regression analysis and resulting hypothesis test takes the form:

$$(\delta_c)_{\rho,t} = \beta_L \cdot r_{L,t} + \beta_H \cdot r_{H,t} + \beta_\delta\,(\delta_c)_{\rho,t-1} + \beta_c\left(\frac{I_{\rho,t-1}}{K_{\rho,t-1}}\right) + \gamma_\rho + \epsilon_{\rho,t} \tag{12}$$

where firms are indexed by subscript $\rho$ and the time period is indexed by subscript $t$. As above $r_L$ and $r_H$ are short and long bond term premiums (i.e., using the ten and five year bond yields, $r_H = r_{10} - r_1$ and $r_L = r_5 - r_1$). The ratio $\frac{I_{\rho,t-1}}{K_{\rho,t-1}}$ is the firm's total new investment expenditure as a proportion of existing capital. Finally, $\gamma_\rho$ is an idiosyncratic error (independent of time and possibly correlated with the explanatory variables) and $\epsilon_{\rho,t}$ is the standard observation-specific error. In comparing equation (11) with equation (12) note that $\beta_L = (\delta_L - \delta_H)\,\alpha_L$ and $\beta_H = (\delta_L - \delta_H)\,\alpha_H$ . Since $\delta_L > \delta_H$ (low durability assets have a high depreciation rate and vice-versa) the sign predictions for $\beta_L$ and $\beta_H$ are the same as those for $\alpha_L$ and $\alpha_H$ .

In this regression analysis the composite depreciation rate $\delta_c$ (a measure of the firm's average capital input durability) is the dependent variable. As foreshadowed above, $\delta_c$ is constructed as a simple ratio of a firm's observed depreciation over its total capital stock.

A prominent issue in moving from the theoretical model to the empirical estimation concerns the model's potentially unrealistic steady state assumption. The assumption is useful in presenting a simplified motivational model but is almost certainly violated empirically. To address this issue I include a lagged dependent variable in equation (12) as well as the investment rate measure ($I_{\rho,t-1}/K_{\rho,t-1}$). These regressors are included to account for potential adjustment costs and potential deviations or shifts in depreciation methodology not directly accounted for in the full adjustment, declining balance methodology used as an abstraction in the above model.[12]

The inclusion of a lagged dependent variable, as well as the underlying dynamic nature of the firms' financial data, preclude the application of standard least squares methods. Regardless of the inclusion of the lagged dependent variable the observation-specific error term ($\epsilon_{i,t}$) is almost certainly serially correlated. Left uncorrected this issue has the potential to bias the standard errors generated (since the model will ascribe too much explanatory power to the regressors). In addition to the bias introduced by autocorrelation in the panel model, any standard least squares estimation of equation (12) will also fail produce a consistent estimator (the distribution of the estimates will not concentrate as the sample size grows). This inconsistency occurs since the estimation equation includes both a lagged dependent variable and panel fixed effects which are potentially endogenous. Additionally, even though it is predetermined with respect to the depreciation rate measure, the investment rate measure employed as an explanatory variable is not likely to be strictly exogenous since investment is largely driven by the replacement of depreciated assets. This introduces another potential bias to standard least squares estimates.

To produce a consistent and unbiased estimation I employ a system "generalized method of moments" (GMM) estimator. This is a dynamic instrumental variable methodology based on the Arellano Bond (1991)/Arellano Bover (1995) style. System GMM addresses both the inconsistency and bias issues by applying instrumentation techniques (using additional lagged variables as instruments) to purge the endogenous effects from the lagged dependent variable and other explanatory variables which are not strictly exogenous. I conduct this estimation following the pedagogical approach outlined by Roodman (2009).

[12] Under a straight-line depreciation methodology (rather than the declining balance methodology presented in the simple model) aggregate investment, even if it is distributed in the same composition as the existing capital stock, will lead to a reduction in the measure $\delta_c$. Since the primary concern of this investigation is how the shape of the yield curve effects the *composition* of investment, and not the aggregate size of that investment I include the investment rate measure as an explanatory variable.

## 5. Estimation Results

Table 1 presents system GMM-based estimation results using data from the Compustat database augmented with U.S. treasury data on government bond yields from 1990 to the present (averaged over the calendar year). Additional information and summary statistics for both the yield curve and Compustat data are presented in appendix B.

The term premiums are treated as strictly exogenous and used as standard instruments under the system GMM methodology. The investment rate is used as a "GMM-style" instrument in the estimation equation along with the lagged dependent variable, as these variables are predetermined but potentially not strictly exogenous following the description in Holtz-Eakin et. al.(1988) and Arellano and Bond (1991).

Table 1: Government Bond Term premiums Effect on Depreciation Rate

| | (1) | (2) | (3) |
|---|---|---|---|
| $r_5$ | -4.3151*** | | -2.3910*** |
| | (0.3298) | | (0.1905) |
| $r_{10}$ | 2.6461*** | -2.3180*** | |
| | (0.2236) | (0.2575) | |
| $r_{30}$ | | 1.6606*** | 1.0751*** |
| | | (0.2042) | (0.1024) |
| $\delta_{\rho,t-1}$ | 0.7872*** | 0.7929*** | 0.7891*** |
| | (0.0099) | (0.0098) | (0.0099) |
| $I_{\rho,t-1}/K_{\rho,t-1}$ | -0.1250*** | -0.1439*** | -0.1322*** |
| | (0.0094) | (0.0093) | (0.0093) |
| Pseudo R-Squared | 0.823 | 0.825 | 0.823 |
| ar1 p-value | 0 | 0 | 0 |
| ar2 p-value | 1.05e-06 | 1.55e-06 | 1.26e-06 |
| ar3 p-value | 0.793 | 0.852 | 0.812 |
| hansen p-value | 0 | 0 | 0 |
| instrument count | 502 | 502 | 502 |

166671 Observations and 20970 Firms.
Robust standard errors in brackets: *** $p<0.01$; ** $p<0.05$; * $p<0.1$
Pseudo R-Squared is the Square of the Pearson Correlation Coefficient

Table 1 presents three sets of estimation results for three distinct measures of low durability (short duration) and high durability (long duration) term premiums, all based on the same reduced form equation (12). The results support the hypothesis described. The negative coefficient estimate for the effect of the shorter term premiums in each pair indicates that an increase in the term premium on shorter term debt (holding all else constant) will lead to a reduction in the firm's composite depreciation rate – indicating a shift to higher durability (longer term) assets. Likewise, the positive coefficient estimate on the longer term premiums in each pair indicates that an increase in the term premium on longer term debt (holding all else constant) will lead to an increase in the firm's composite depreciation rate.

Different measures of term premiums are used in the varying estimation results to account for the fact that references to "high" and "low" durability capital (and the associated term premiums) represent a potentially significant abstraction from reality. By estimating the model using a variety of term premiums I show that the result is robust to a general case of a short and long duration term premium regardless of the specific measures used.[13]

The results based on the five year and ten year term premiums (column 1) indicate that a 1% increase in the five year term premium (i.e.- from 1% to 2%) leads to a 4.3% average reduction in firms' composite depreciation rate (i.e.- from 23% to 19%). The results also indicate that a 1% increase in the ten year term premium leads to a 2.6% average increase in firms' composite depreciation rate. Columns two and three of Table 1 show the pattern is consistent for different measures of long and short duration term premiums.

Table 6 in the appendix presents an additional six sets of estimates (nine in total), all based on equation (12). A set of results is presented for i) each of the three distinct measures of low durability (short duration) and high durability (long duration) term premiums and ii) three distinct structures of the instrument set. Model estimates for the different instrument set structures are included to acknowledge potential invalidity of the full instrument set. Roodman (2006, 2009), cautions that proliferation in the number of included instruments can over-fit the endogenous variables, failing to correct the problem for which their use is intended. This is especially likely in longer panels as the total instrument count rises with the time dimension. The estimated pattern is consistent across the full and limited instrument sets indicating that

[13]Two additional sets of estimates (not reported here) use other bond yield data and also provide consistent results. These estimates use i) corporate bond yield averages from the Federal Reserve Economic Data service (http://research.stlouisfed.org/fred2/) and ii) fitted government bond yields going back to 1961 provided by Gurkaynak et. al. (2007). These results are available upon request.

proliferation is not a significant issue in this case.[14]

Both the summary results (Table 1) and full results in the appendix (Table 6) provide p-values for the Arellano-Bond test for autocorrelation in the first differences of the idiosyncratic error term. The positive test for AR(2) indicates that the level values of the error term ($\epsilon_{\rho,t}$) are endogenous to their lagged values ($\epsilon_{\rho,t-1}$).[15] This indicates that either the lagged dependent variable ($\delta_{\rho,t-1}$) or the investment rate ($I_{\rho,t-1}/K_{\rho,t-1}$) are endogenous to the lagged error ($\epsilon_{\rho,t-1}$). This outcome is expected since investment is likely driven in large part by depreciation. To account for this potential invalidity of instruments, the instrument set is restricted to using lags two and longer of the gmm-style variables.

The panel is unbalanced and displays both entry and exit of firms. Because of this it is likely that changes in the term premiums, while orthogonal to the idiosyncratic error term, may not be orthogonal to the individual fixed effect of the firm. The potential tendency for different industries to favor production with high or low durability capital could cause firms to enter or exit based on the current shape of the yield curve. Such a relationship would make the fixed effect endogenous to the assumed exogenous regressors $r_L$ and $r_H$. To avoid this issue, the term premiums are used in the orthogonality conditions for the differenced equation and not the levels equation.

The results are generally robust to the elements of the instrument matrix (as indicated by table 6) so the preferred specification will be one that uses the entire set of lags. When instrument proliferation fails to be a significant issue more lags are generally preferred, to introduce more information and by extension improve the efficiency of the estimator. As noted the magnitude and statistical strength of the estimated effect is largest in column 1 of table 6 indicating that on average firms are more sensitive to the $r_5, r_{10}$ pair than the other pairs examined. Additionally,

[14]Both the Hansen and Sargen tests of overidentification restrictions (unreported) reject the null hypothesis of exogeneity of the instrument sets for all regressions presented. This is expected due to the nature of the data generating process including both new investment (a portion of which replaces depreciated assets) and a lagged dependent variable. The difference-in-Hansen test for exogeneity of the of the IV style variables ($r_L$ and $r_H$) produces acceptable p-values (in the range of 0.26) for the estimates generated using the full instrument set (columns three, six and nine in Table 1). This indicates that the instrument set is valid insofar as only $r_L$ and $r_H$ are assumed exogenous.

[15]In the estimation of equation 12 changes in $\epsilon_{\rho,t}$ are systematically related to changes in $\epsilon_{\rho,t-1}$ given the dynamic nature of the equation. This is confirmed by the AR(1) test p-value and does not pose a problem for the desired properties of the estimates. See Roodman (2006)

since the shorter term premiums in the dataset display a higher variance than longer term rates, the pairing $r_5$ and $r_{10}$ provide a better source of exploitable variation to identify the relationship in question.

Table 2: Government Bond Term premiums Effect on Depreciation Rate: By Size of Firm (Quintiles)

| VARIABLES | (1)<br><20% | (2)<br>20%<40% | (3)<br>40%<60% | (4)<br>60%<80% | (5)<br>80%< |
|---|---|---|---|---|---|
| $r_5$ | -14.9446*** | -7.0901*** | -4.9594*** | -3.4789*** | -2.6268*** |
| | (1.6548) | (0.9757) | (0.7221) | (0.5706) | (0.4173) |
| $r_{10}$ | 9.8110*** | 4.6704*** | 3.2670*** | 2.2715*** | 1.7286*** |
| | (1.1330) | (0.6711) | (0.4908) | (0.3907) | (0.2831) |
| $\delta_{\rho,t-1}$ | 0.7838*** | 0.7674*** | 0.6853*** | 0.7382*** | 0.7551*** |
| | (0.0287) | (0.0199) | (0.0214) | (0.0281) | (0.0334) |
| $I_{\rho,t-1}/K_{\rho,t-1}$ | -0.2432*** | -0.1398*** | -0.0559*** | -0.0208 | 0.0209 |
| | (0.0533) | (0.0269) | (0.0193) | (0.0166) | (0.0142) |
| Observations | 28,077 | 32,762 | 34,238 | 35,257 | 36,337 |
| Number of gvkey | 7,065 | 8,304 | 7,711 | 6,262 | 3,929 |
| Pseudo R-Squared | 0.787 | 0.819 | 0.815 | 0.808 | 0.798 |
| ar1 p-value | 0 | 0 | 0 | 0 | 0 |
| ar2 p-value | 0.00693 | 0.0931 | 0.168 | 0.0741 | 0.0392 |
| ar3 p-value | 0.497 | 0.227 | 0.550 | 0.678 | 0.960 |

Robust standard errors in brackets: *** p<0.01; ** p<0.05; * p<0.1
Pseudo R-Squared is the Square of the Pearson Correlation Coefficient
Observation specific percentiles are calculated by estimating a distribution function

The results of a quintile regression based on firm size (total capital stock) and are presented in Table 2. These estimates use the $r_5$, $r_{10}$ pairing and employ a collapsed instrument set. Since the segmented samples are smaller in the quintile regression the instrument set is collapsed to a single vector, sacrificing some estimation efficiency to ensure that instrument proliferation does not become an issue.

Again the signs of the estimated coefficients match with the hypothesized outcome, however; the magnitudes vary considerably across firm size. Small firms exhibit a very strong relationship between changes in the term premiums and composite depreciation with an estimated coefficient on the short term premium ($r_5$) of $-14.94$ and an estimated coefficient on the long-term premium ($r_{10}$) of 9.81. These magnitudes shrink considerably as we examine higher quintiles. For the largest firms the estimates are $-2.63$ ($r_5$) and 1.73 ($r_{10}$) suggesting that larger firms are less responsive to changes in the term premiums associated with government bonds. A potential explanation could lie in larger firms' ability to access international capital markets, which would imply that U.S. Bond Term premiums are less correlated with the opportunity cost of capital of different durations faced by those firms. It could also be the case that firm growth and maturity, as well as entry and exit (small firms are more likely to have recently entered or to have exited the market) are partially responsible for this result.

Table 3: Government Bond Term premiums Effect on Depreciation Rate: By Industry

| Industry | $r_5$ | | $r_{10}$ | | Firms | Pseudo $R^2$ |
|---|---|---|---|---|---|---|
| Mining | -3.3914*** | (1.1963) | 2.0556** | (0.8743) | 15,244 | 0.822 |
| Construction | -6.7002** | (3.3627) | 3.3912 | (2.3259) | 2,217 | 0.796 |
| Manufacturing | -5.6147*** | (0.5332) | 3.5060*** | (0.3676) | 63,466 | 0.806 |
| Wholesale Trade | -3.7273** | (1.8255) | 2.3114* | (1.2465) | 5,702 | 0.818 |
| Retail Trade | -2.0546** | (0.9384) | 1.1933* | (0.6567) | 7,544 | 0.782 |
| Transport & Warehousing | -1.2138 | (0.9254) | 0.6778 | (0.6293) | 4,663 | 0.816 |
| Information | -8.4204*** | (1.6457) | 5.0793*** | (1.2027) | 15,692 | 0.703 |
| Real Estate | -5.5487*** | (2.0545) | 3.5359** | (1.4067) | 3,394 | 0.679 |
| Tech Services | -6.1528*** | (2.3579) | 3.0935* | (1.6368) | 6,683 | 0.698 |
| Admin Waste Remediation | -5.9802** | (2.7911) | 3.0271 | (1.9617) | 3,219 | 0.772 |
| Education | -5.1416 | (4.6080) | 2.5631 | (3.0443) | 611 | 0.756 |
| Health Care | -4.7381** | (2.0229) | 2.8057** | (1.3410) | 2,888 | 0.817 |
| Arts and Entertainment | -3.7251 | (2.5829) | 2.6374 | (1.7253) | 1,193 | 0.679 |
| Accomodation and Food | -1.5161 | (1.1309) | 0.9833 | (0.7522) | 3,440 | 0.818 |
| Other | -1.8569 | (3.7405) | 0.5956 | (2.5071) | 657 | 0.736 |
| Agriculture | 2.3109 | (3.4001) | -1.5012 | (2.3571) | 638 | 0.807 |
| Utilities | 0.9091* | (0.5453) | -0.7982** | (0.3845) | 6,949 | 0.824 |

Robust standard errors in brackets: *** p<0.01; ** p<0.05; * p<0.1
Pseudo R-Squared is the Square of the Pearson Correlation Coefficient

As a robustness check (and to identify if the relationship is markedly different across industries) the estimation is conducted across subsamples based on two digit SIC codes as reported in the Compustat database. The estimated coefficients for each individual industry are displayed in Table 3.[16] An examination of these results indicates that, with very few exceptions, different industries follow the average trend identified in the pooled regression. Where the expected relationship is identified the magnitude of the estimated coefficient on the short term premiums ($r_5$) ranges from $-1.2$ (transportation and Warehousing) to $-8.42$ (Information). Likewise, the estimated coefficient on the long-term premiums ($r_{10}$) ranges from 0.6 (Transportation and

[16]Since the segmented samples are smaller in these industry specific samples, the instrument set is collapsed to a single vector sacrificing some estimation efficiency to ensure that instrument proliferation does not become an issue in these estimates.

Warehousing) to 5.08 (Information).

Of the 17 subgroup industry classifications identified, the estimates for the Utilities sector present the only statistically significant deviation from the hypothesis outlined above.[17]

## 6. Conclusion

The results presented above confirm the assertions that i) capital inputs with different depreciation rates are associated with different opportunity costs of capital following the bond yield curve and ii) firms choose the desired stock of each heterogeneous capital input based on these heterogeneous costs of capital. I find evidence to support the hypothesis that firms adjust composition of their capital input stock between high and low durability capital in response to changes in term premiums on long and short term debt.

These results carry an important implication in establishing evidence that firms have a degree of substitutability in the production/revenue function between capital inputs with different associated durabilities. This substitutability allows them to respond to changes in the relative costs of long and short term capital as observed in the data. A major implication of these results is the fact that open market operations have a heretofore unrecognized effect on the durability of capital investments made by firms.

Monetary authorities should therefore consider these effects when undertaking actions that are intended to dramatically change the shape of the yield curve. Initiatives like Operation Twist-1961, Operation Twist-2011 and the three successive rounds of quantitative easing between 2008 and 2012 are likely to have significantly impacted the average durability of capital invested by U.S. firms. Regardless of their success in effecting the targeted macroeconomic indicators these programs likely impacted the composition of firms capital stocks with respect to durability.

[17] The agriculture industry also has estimated coefficient with signs opposite to the prediction, however; the small relative sample size and lack of any reasonable level of statistical significance imply that the result is not too damaging to the hypothesized relationship. In the case of the Utilities sector, I find the result surprising. An earlier version of this work, presented as a working paper and using plant level data on electricity generators in the United States, generated results consistent with the hypothesis established above indicating the need for more work in this area.

## A. Second and Third Order Conditions of $\alpha = f(r_L, r_H)$

Given the existence of own and cross price effects and the lack of good data on the capital composition of firms it is likely that any reasonably constructed structural estimation model based on equations (6) would require more data than is commonly available. Abstracting to a linear relationship, as in equation 11, overcomes the problems associated with a more complex structural estimation but carries the potential deficiency that the abstraction ignores potential second order effects. Without adding additional structure to the modeled production function, it is not possible to analytically quantify this potential bias. Unfortunately adding such structure is undesirable for two reasons. First, given the very wide range of firms and sectors represented in the CompuStat data a single production function structure (even if it allows for heterogeneous parameter values) is unlikely to represent an acceptable model for all firms. Second, adding additional structure has the potential to imply or presuppose the result being tested for.

Regardless, so long as the second order effects $\left(\frac{\partial^2\alpha}{\partial r_i^2}\right)$ are stable (i.e.- the third order effects are equal to or approximately zero $\left(\frac{\partial^3\alpha}{\partial r_i^3} \approx 0\right)$ the error in the linear approximation of $\alpha$ will be orthogonal to the term premiums and the nonlinearity should not bias the empirical estimates under the system GMM estimator employed.

While an attempt to more structurally define and fit the model is potentially appealing, the linearized version allows the empirical model to remain largely agnostic in construction insofar as the predicted relationship between $\delta_c$ and the term premiums.

## B. Summary Statistics

Firm level financial data on depreciation and investment rates used in the empirical analysis are all constructed using total property, plant and equipment as well as depreciation data from the CompuStat database (http://www.compustat.com). Summary statistics for the constructed measures are given in Table 4. The estimates and summary statistics here are presented for active firms only and for firms with calculated depreciation rates between 0% and 100%.

The CompuStat data is merged with information on the shape of the U.S. bond yield curve,

Table 4: Summary Statistics: Yearly Average U.S. Bond Yields and associated Term premiums

| VARIABLES | mean | sd | min | max | p10 | p90 |
|---|---|---|---|---|---|---|
| Depreciation and Amortization | 136.2 | 732.5 | 0 | 33,751 | 0.206 | 206.0 |
| Property, Plant and Equipment - Total (Net) | 1,118 | 5,534 | 0.001 | 256,834 | 1.168 | 1,864 |
| Depreciation Rate | 22.66 | 18.98 | 0 | 100 | 5.112 | 50 |
| Investment Rate | 28.02 | 23.33 | 0 | 100 | 1.291 | 63.20 |

146,470 Observations and 18,806 firms
Values are millions of dollars -first two rows- and percentage points -second two rows

readily available from the U.S. Treasury. Historical Daily Treasury Yield Curve Rates are available on-line from:

http://www.treasury.gov/resource-center/data-chart-center/interest-rates/Pages/TextView.aspx?data=yield

The Treasury provides the bond yield data at a daily frequency. To match the annual frequency of the plant level data I convert these yields by taking a simple day to day average over the year.

Table 5: Summary Statistics: Yearly Average U.S. Bond Yields and associated Term premiums

| VARIABLES | N | mean | sd | min | max | p10 | p90 |
|---|---|---|---|---|---|---|---|
| (mean) oneyear | 24 | 3.523 | 2.314 | 0.131 | 7.887 | 0.181 | 5.942 |
| (mean) fiveyear | 24 | 4.491 | 2.063 | 0.762 | 8.373 | 1.518 | 6.688 |
| (mean) tenyear | 24 | 5.058 | 1.748 | 1.803 | 8.552 | 2.782 | 7.085 |
| (mean) thirtyyear | 24 | 5.590 | 1.493 | 2.922 | 8.610 | 3.911 | 7.666 |
| $r_5$ | 24 | 0.969 | 0.693 | -0.187 | 2.297 | 0.0448 | 1.725 |
| $r_{10}$ | 24 | 1.536 | 1.056 | -0.141 | 3.120 | 0.103 | 2.791 |
| $r_{30}$ | 24 | 2.068 | 1.372 | -0.172 | 3.933 | 0.307 | 3.730 |

all values are percentage points

Summary statistics for the annual averaged yield curve rates and the calculated term premiums are given in Table 5. There is no available data on 30 year government bond yields for the years 2003,2004 and 2005. The 30 year premiums for these years is proxied using changes in the twenty year term premiums via the following formula: $r_{30,t} = r_{30,t-1} + (r_{20,t} - r_{20,t-1})$

# C. Supplementary Estimates

Table 6: Government Bond Term premiums Effect on Depreciation Rate: Full, Collapsed and Collapsed/Restricted Lag Structures

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| $r_5$ | -9.3547*** | -7.9698*** | -4.3151*** | | | | -5.1660*** | -4.4116*** | -2.3910*** |
| | (0.4316) | (0.3790) | (0.3298) | | | | (0.2489) | (0.2199) | (0.1905) |
| $r_{10}$ | 6.1900*** | 5.2148*** | 2.6461*** | -5.6093*** | -4.8031*** | -2.3180*** | | | |
| | (0.2945) | (0.2582) | (0.2236) | (0.3319) | (0.3007) | (0.2575) | | | |
| $r_{30}$ | | | | 4.3562*** | 3.6949*** | 1.6606*** | 2.6603*** | 2.2255*** | 1.0751*** |
| | | | | (0.2658) | (0.2401) | (0.2042) | (0.1358) | (0.1195) | (0.1024) |
| $\delta_{\rho,t-1}$ | 0.7424*** | 0.7459*** | 0.7872*** | 0.7572*** | 0.7599*** | 0.7929*** | 0.7464*** | 0.7501*** | 0.7891*** |
| | (0.0109) | (0.0108) | (0.0099) | (0.0107) | (0.0106) | (0.0098) | (0.0108) | (0.0107) | (0.0099) |
| $I_{\rho,t-1}/K_{\rho,t-1}$ | -0.0231* | -0.0489*** | -0.1250*** | -0.0658*** | -0.0837*** | -0.1439*** | -0.0353*** | -0.0600*** | -0.1322*** |
| | (0.0124) | (0.0119) | (0.0094) | (0.0119) | (0.0115) | (0.0093) | (0.0123) | (0.0118) | (0.0093) |
| Lag Structure | Collapsed 3-7 | Collapsed 3-. | 3-. | Collapsed 3-7 | Collapsed 3-. | 3-. | Collapsed 3-7 | Collapsed 3-. | 3-. |
| Pseudo R-Squared | 0.803 | 0.810 | 0.823 | 0.816 | 0.819 | 0.825 | 0.808 | 0.814 | 0.823 |
| ar1 p-value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ar2 p-value | 1.40e-06 | 1.35e-06 | 1.05e-06 | 1.26e-06 | 1.41e-06 | 1.55e-06 | 1.38e-06 | 1.39e-06 | 1.26e-06 |
| ar3 p-value | 0.661 | 0.677 | 0.793 | 0.724 | 0.744 | 0.852 | 0.673 | 0.693 | 0.812 |
| hansen p-value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| instrument count | 12 | 42 | 502 | 12 | 42 | 502 | 12 | 42 | 502 |

166671 Observations and 20970 Firms.
Robust standard errors in brackets: *** p<0.01; ** p<0.05; * p<0.1
Pseudo R-Squared is the Square of the Pearson Correlation Coefficient

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