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A production-based model for the term structure ☆

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ABSTRACT

This paper considers the term structure of interest rates implied by a production-based asset pricing model in which the fundamental drivers are investment in equipment and structures as well as inflation. The model matches the average yield curve up to five-year maturity almost perfectly. Longer term yields are roughly as volatile as in the data. The model also generates time-varying bond risk premiums. In particular, when running Fama-Bliss regressions of excess returns on forward premiums, the model produces slope coefficients of roughly half the size of the empirical counterparts. Closed-form expressions highlight the importance of the capital depreciation rates for interest rate dynamics.

1. Introduction

Many models exist of the term structure of interest rates, but only a few tie interest rates to macroeconomic fundamentals. Among fundamentals-based models, most are driven by consumption. Given the relative success of production-based models in matching features of stock returns at the aggregate level and in the cross section, extending the production-based approach to the term structure of interest rates seems promising.

Consumption-based models of the term structure face a number of difficulties. Many of these are related to the equity premium puzzle (Mehra and Prescott, 1985), according to which empirically reasonable consumption volatility and risk aversion are too small to match the sizable historical equity premium. Backus, Gregory, and Zin (1989) find that complete markets models cannot explain the sign, the magnitude, or the variability of the term premium. In this class of models, expected consumption growth and real yields are positively correlated. Chapman (1997) reports some supportive evidence for this property, as do Berardi and Torous (2005). Considering richer model specifications, several more recent studies report more positive results for explaining term premiums; for instance, Wachter (2006), Bansal and Shaliastovich (2010), Piazzesi and Schneider (2007), Ehling, Gallmeyer, Heyerdahl-Larsen, and Illeditsch (2013), and Rudebusch and Swansson (2008). General equilibrium models that start from a consumption-based model and add elements of endogenous production still face difficulties with jointly explaining the term structure and macroeconomic aggregates, as shown in van Binsbergen, Fernandez-Villaverde, Koijen, and Rubio-Ramirez (2010).

Production-based asset pricing models have linked stock returns to fundamentals such as investment and productivity. Cochrane (1991) establishes the link between a firm's return to investment and its market return. He also shows a tight empirical relation between aggregate investment and stock returns. Production-based models have been used to explain the value premium (Zhang, 2005), and properties of external financing behavior (Li, Livdan,

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and Zhang, 2009). Production-based models have also shown to be useful for understanding the cross section of stock returns more generally. See, for instance, Berk, Green, and Naik (1999), Liu, Whited, and Zhang (2009), Belo (2010), Tuzel (2010), and Eisfeldt and Papanikolaou (forthcoming).[1]

The objective of this paper is to extend the production-based approach to price nominal bonds of different maturities. Specifically, this paper builds on Jermann (2010), which analyzes the determinants of the equity premium and presents a model that can quantitatively match first and second moments of the real returns on stocks and short-term real bonds. I start from the same two-sector investment model based on equipment and structures. The paper here extends the analysis to the term structure of nominal bonds and explicitly introduces inflation. The paper is also related to Cochrane's (1988) working paper that presents a two-sector investment model and shows that the real forward premium from the model can track well its empirical counterpart over 1952–1986. In my paper, I present a more detailed analysis of the term structure, explicitly introduce inflation, and consider nominal bonds. The real side of the model is also more general. Importantly, I allow for general curvature in the capital adjustment cost functions as opposed to Cochrane's quadratic specification.

The main quantitative findings are that the model, calibrated to match the equity premium and the volatility of stock returns as well as the mean and volatility of short-term yields, matches the average yield curve up to five-year maturity almost perfectly. Longer-term yields are roughly as volatile as in the data. The model also generates time-varying bond risk premiums. In particular, when running Fama-Bliss regressions of excess returns on forward premiums, the model produces slope coefficients of roughly half the size of the empirical counterparts.

My model is a two-sector version of a q-theory investment model. Firms' optimal investment choices generate the well-known equivalence between market returns and investment returns. The short-term real risk-free rate can be seen as a long–short portfolio of the two risky investment returns. With the help of a continuous-time version of the model, the economic forces that drive the quantitative results are revealed explicitly. In particular, the short rate is shown to be a weighted average of the two expected investment returns, with weights that are constant and simple functions of the adjustment cost curvature parameters. Expected returns and the market price of risk are driven by the two investment-to-capital ratios that display important low-frequency components. The volatility of the short rate is also a function of the investment-to-capital ratios. Thus, even with homoskedastic shocks, the model endogenously produces time-varying bond risk premiums. A key new finding is that the difference in depreciation rates between structures and equipment plays a crucial role for whether interest rates commove positively or negatively with investment and for whether the implied term premium for bonds with a short maturity is positive or negative.

The paper proceeds as follows. Section 2 presents the model; Section 3, the quantitative analysis. Section 4 analyzes a continuous-time version of the model. Section 5 concludes.

2. Model

This section starts by presenting the real side of the model, which was first used in Jermann (2010). Inflation is then introduced.

2.1. Real model

Assume an environment in which uncertainty is modeled as the realization of s, one out of a set of two (s_1, s_2), with s_t the current period realization and $s^t \equiv (s_0, s_1, \ldots s_t)$ the history up to and including t. Assume a revenue function with two capital stocks $K_j(s^{t-1})$ for $j = 1,2$,

$$F(\{K_j(s^{t-1})\}_{j\in(1,2)}, s^t) = \sum_{j=1}^{2} A_j(s^t) K_j(s^{t-1}). \tag{1}$$

As is standard, $K_j(s^{t-1})$ is chosen one period before it becomes productive. $F(\cdot)$ represents the resources available after the firm has optimally chosen and paid factors of production that are selected within the period, for instance, labor.[2] $A_j(s^t)$ is driven by productivity shocks and other factors affecting the marginal product of capital. It is key that there are as many capital stocks as there are states of nature next period. Without this property, recovering state prices from the firm's production choices would not be possible.

Capital of type j accumulates through

$$K_j(s^t) = K_j(s^{t-1})(1-\delta_j) + I_j(s^t), \tag{2}$$

where δ_j is the depreciation rate and $I_j(s^t)$ is investment. The total cost of investing in capital of type j includes convex adjustment costs and is given by

$$H_j(K_j(s^{t-1}), I_j(s^t)) = \left\{ \frac{b_j}{\nu_j} (I_j(s^t)/K_j(s^{t-1}))^{\nu_j} + c_j \right\} K_j(s^{t-1}), \tag{3}$$

with $b, c > 0$, $\nu > 1$. For each capital stock, different values for b, c, and ν are allowed. The most important parameter is the curvature ν, as it determines the volatility of percentage changes in the marginal adjustment cost, and thus Tobin's q, relative to investment volatility. The other parameters play a minor role for the main asset pricing properties this paper focuses on.

Taking as given state prices $P(s^t)$, a representative firm solves the problem

$$\max_{\{I,K'\}} \sum_{t=0}^{\infty} \sum_{s^t} P(s^t) \left[F(\{K_j(s^{t-1})\}_{j\in(1,2)}, s^t) - \sum_{j=1}^{2} H_j(K_j(s^{t-1}), I_j(s^t)) \right] \tag{4}$$

[1] For additional examples of the production-based approach applied to stocks, see Carlson, Fisher, and Giammarino (2004), Li, Vassalou, and Xing (2006), Warusawitharana (2010), Kogan (2004), Cooper (2006), Pastor and Veronesi (2009), Kuehn (2009), and Eberly and Wang (2010).

[2] This revenue function could, for instance, be derived from a production function $(\sum_j a_{j,t} K_{j,t})^{\alpha} N_t^{1-\alpha}$, where $a_{j,t}$ are shocks, $0 < \alpha < 1$, and labor N is paid its marginal product.