Quantitative Monographs

A quantitative approach to equity valuation

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The typical equity valuation involves so much uncertainty that the results are arbitrary for practical purposes. The ubiquitous discounted cash flow model is so sensitive to its inputs that any desired valuation can be produced, all with seemingly reasonable inputs and assumptions. In this light, perhaps it is no surprise that investors are sceptical about the conclusions drawn from valuation process.

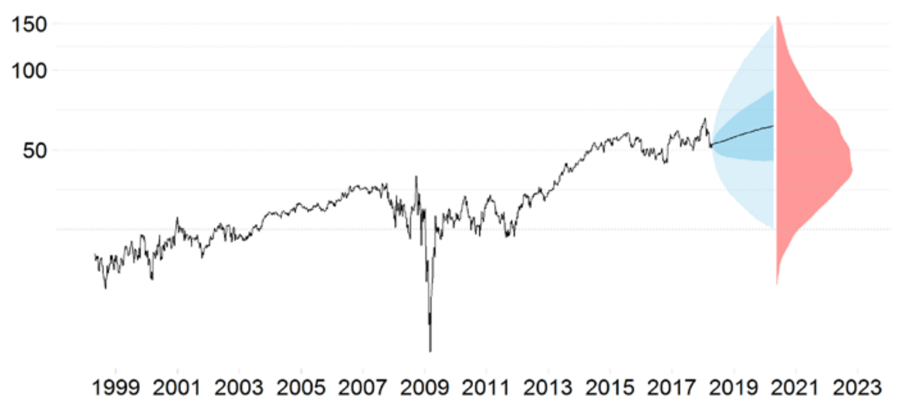
The Bayesian valuation

We introduce a novel technique to account for this uncertainty in the valuation process, using a modern statistical inference platform. This provides a framework by which we can include any accounting identities, market-implied estimates, fundamental insights, econometric models and so on. This application presents itself as a rich confluence of the quantitative and fundamental investment approaches.

Modelling the investment horizon

We walk through a probabilistic valuation process step-by-step, discussing the benefits and shortcomings of the results along the way. Our resulting model produces a directly useful output, which is significantly more informative than the conventional approach. Using this framework, we can now explicitly model the investment horizon over which a valuation is expected to materialise, using a price forecasting model and the Kullback-Leibler divergence—which is difficult with the traditional process.

Figure 1: The price forecast (blue), and valuation (red) distributions



Source: UBS Quant

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Introduction

Valuation is fraught with uncertainties and assumptions; it is perhaps no surprise that many investors are sceptical of how arbitrary the conclusions are. In this report we introduce a method for modelling uncertainty in the equity valuation process, so that we might better understand the uncertainty in the output.

Equity valuations seem almost arbitrary given similar inputs

Consider a portfolio manager faced with the following investment opportunities: two stocks with expected returns of 10% and 15%, respectively. Obviously the 15% prospect is more attractive given no other information; however this scenario does not describe the uncertainty in each of these forecasts.

Point estimates are almost exclusively adopted in finance

Below we show two probability densities corresponding to such outcomes; the first has a mean of 10% and the second has a mean of 15% (albeit with a 19% chance of losing more than 50%); the same portfolio manager would likely now prefer the former option over the latter, given it has far less downside risk.

Forecast uncertainty is seldom accounted for, much less quantified

Figure 2: Investment 1, expected return 10%

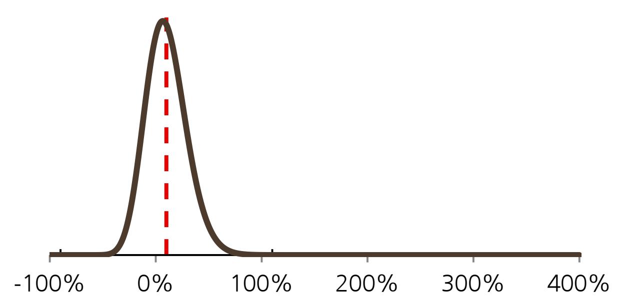

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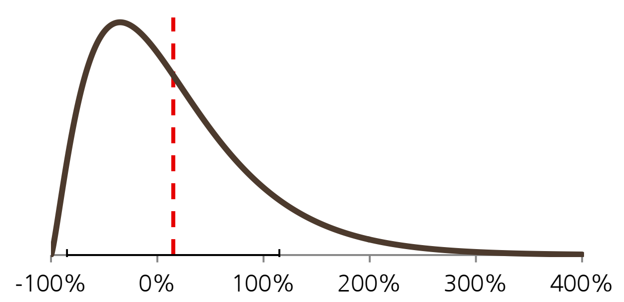
Figure 3: Investment 2, expected return 15%



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The obvious shortcomings of point forecasts have long been recognised; however computational advances have only recently unlocked new tools for understanding and modelling uncertainty. There is significant uncertainty in the equity valuation process which is commonly ignored; we believe that this opportunity presents itself as a rich confluence of the quantitative and fundamental investment approaches.

This is a rich confluence of the quantitative and fundamental investment approaches

The Dividend Discount Model (DDM)

The DDM defines the value of a stock as its total expected cash dividends paid into perpetuity, discounted by the cost of equity k_e

$$Stock\ value = \sum_{t=1}^{\infty} \frac{E[DPS_t]}{(1+k_e)^t}$$

The Gordon Growth Model (GGM)

The Gordon Growth Model is a simplification of the dividend discount model that assumes a constant cost of equity (k_e) slightly more than the perpetual dividend growth rate (g). Under these conditions, the geometric series above converges to:

$$Stock\ value = \frac{E[DPS_{t=1}]}{k_e - g} = DPS_{t=0}\frac{1+g}{k_e - g}$$

$$Upside = \frac{Stock\ Value}{Current\ Price} - 1 = Div.Yield \cdot \frac{1+g}{k_e - g} - 1$$

The obvious attraction of this model is its simplicity and intuition; however it is not without its critics. The primary concerns are the strong assumptions that it makes, and the extreme sensitivity to its inputs.

Simple and intuitive, but highly sensitive

The conventional approach

The conventional approach to valuing equities with the GGM looks like this:

- The risk-free rate measured by the average US 10Y yield is 3.6%
- The beta of the security is 1.3
- The equity risk premium (ERP) is 5%
- The company is stable with annual dividend growth of 7%
- The current dividend yield is 3%
- So the implied cost of equity is $3.6\% + 1.3 \times 5\% = 10.1\%$
- Thus the valuation upside is $3\% \times (100 + 7)/(10.1 - 7) - 1 = +3.5\%$

Thus despite the questionable assumptions and merely approximately-known input data, we arrive at an *impossibly precise* measurement of the company valuation relative to the current market price.

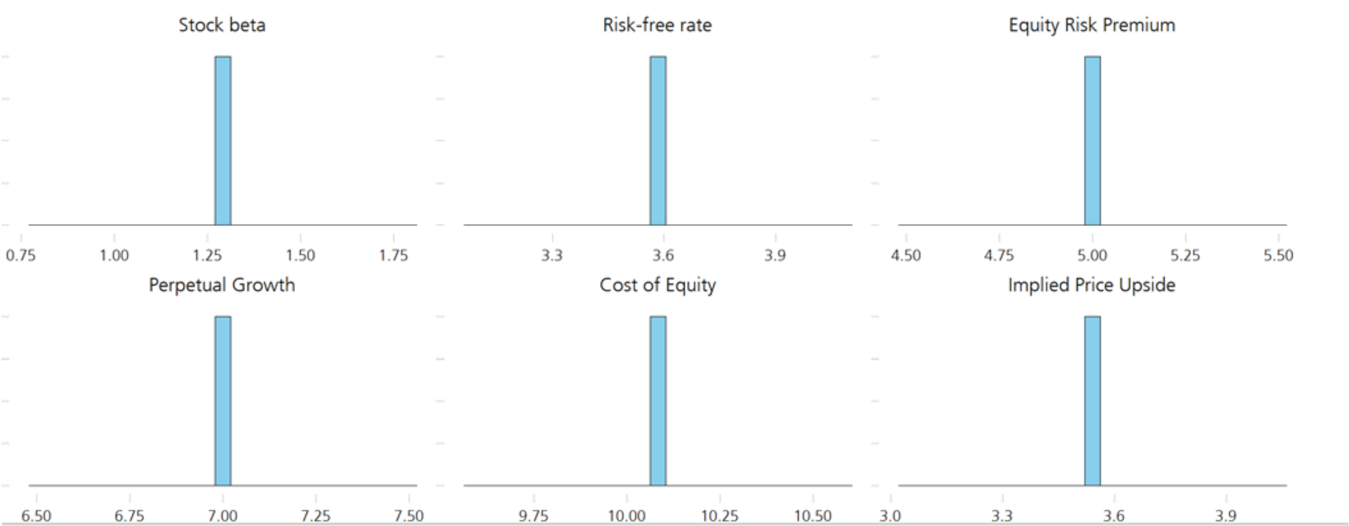
We quickly arrive at an impossibly precise valuation

However these quantities are *not fixed and known* as the model suggests, and the output is highly sensitive to these inputs. For example, the equity risk premium is a crude approximation at best and unobservable at worst—there is ongoing debate as to its proper calculation. Yet if the ERP above were 4.5%, the valuation upside then becomes +31%.

The inputs are not fixed and known; often we have deep insights into their values

If these parameters are all assumed to be known precisely then we arrive at a precise valuation. Yet each of the inputs above is only an estimate—the true value is unknown. Thus the conventional approach has significant shortcomings, as illustrated in Figure 4.

Figure 4: The traditional approach implies resolute certainty



Source: UBS Quant

So far, nothing is new here. The problems with this method are well-known—yet despite its shortcomings this model remains in use today.

Accounting for uncertainty

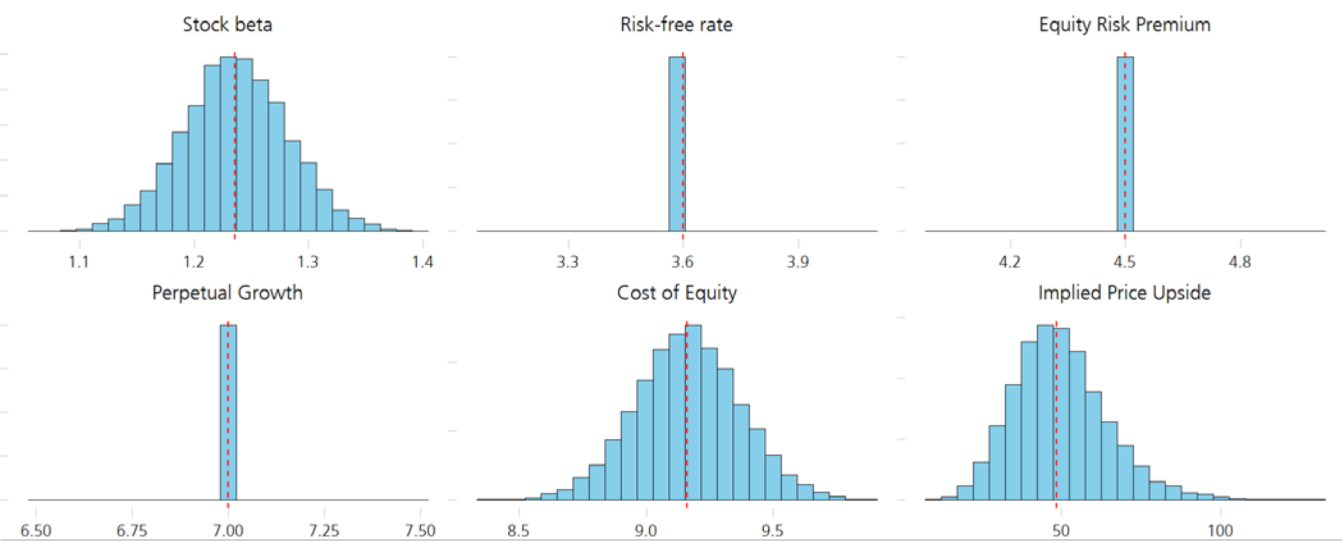
"It's better to be approximately right than exactly wrong" - Carveth Read

However using a flexible and powerful Bayesian computational framework known as Stan[1], we can undertake rich probabilistic modelling, incorporating accounting identities, extensive domain knowledge, market-implied estimates, and so on.

To illustrate this with an example, we take the same inputs as above but instead of assuming that the beta is precisely known, we now simply estimate it using a Bayesian linear regression of the CAPM. Figure 5 shows the subsequent impact on the valuation by introducing this simple step.

We keep the model as above, but now estimate the beta using a Bayesian regression of the CAPM

Figure 5: The impact of estimating the CAPM stock beta



Source: UBS Quant

Evidently the estimated beta with a mean of 1.24 is slightly lower than our earlier assumption of 1.3[2]. The subsequent impact on the upside is dramatic; the resulting cost of equity (ie, the discount rate) was consequently too high and the valuation was depressed accordingly. Our earlier estimate of the implied price upside was at the low end of the range, with expected upside of not 3.5% but now 50%.

Introducing the uncertainty in just one parameter dramatically changes the outcomes

While this is only a simple example, we show how the apparent certainty of the valuation belies the uncertainty of the inputs; our precise forecasts of the risk-free rate, equity risk premium and perpetual growth assumptions are equally open to challenge. We can further incorporate any economic modelling or forecasting to describe the equity risk premium and its uncertainty, or any fundamental insights to describe the terminal growth rate of the company.

Any active views we might have on the other model inputs can be implemented in the model

Figure 6 shows the full probabilistic GGM valuation of the company above using structural time-series models for the risk-free and dividend growth stream; these are robust and intuitive, which is critical to bridging the "quantamental" divide.

We adopt structural time-series models to robustly estimate

[1] Stan Development Team. 2017. The Stan Core Library, Version 2.17.0. http://mc-stan.org

[2] A beta of 1.3 is actually the 92nd percentile of the empirical distribution, ie, 92% of the simulated draws from the posterior are less than 1.3. While in nominal terms it appears as a close result, the impact on the resulting valuation is considerable

The equity risk premium is simply estimated as the difference between the annual long-run historical equity market return and the average US 10Y bond yield. In our subsequent research we may explore a more refined, ex-ante definition of the equity risk premium, eg, using implied volatility from options prices, credit spreads or even incorporating survey data directly into the valuation model.

Figure 6: The uncertainty of the valuation inputs

Source: UBS Quant

The price upside has a significant variance; this is not the lack of information

We note several features in this result. Once the uncertainty in all the parameters have been taken into account, the price upside output has significant variation; so much as to be ineffective for practical purposes. The price upside now has a median of 120%, with lower quartile of 39% and upper quartile of 280%. Much of this uncertainty is driven by the equity risk premium (which is itself poorly defined), and the constraint that the resulting cost of equity is larger than the perpetual dividend growth rate.

Ignoring the uncertainty does not make it disappear

While this seems an underwhelming result thus far, we gain nothing by shrouding the inherent valuation uncertainty in misguided convictions—ignoring it does not make it disappear. Following best practices, we incrementally refine our model to address the deficiencies of the preceding models, and incorporate more domain knowledge.

The GGM does not describe the data well thus far

Note the expected growth of the dividends is inconsistent with our understanding of economics. *A company cannot continue to grow its dividends or earnings at 8% into perpetuity as this result suggests*; its perpetual growth is effectively bounded from above by nominal economic growth. It appears our model has approached a limit of what we can reasonably expect it to explain in the equity valuation.

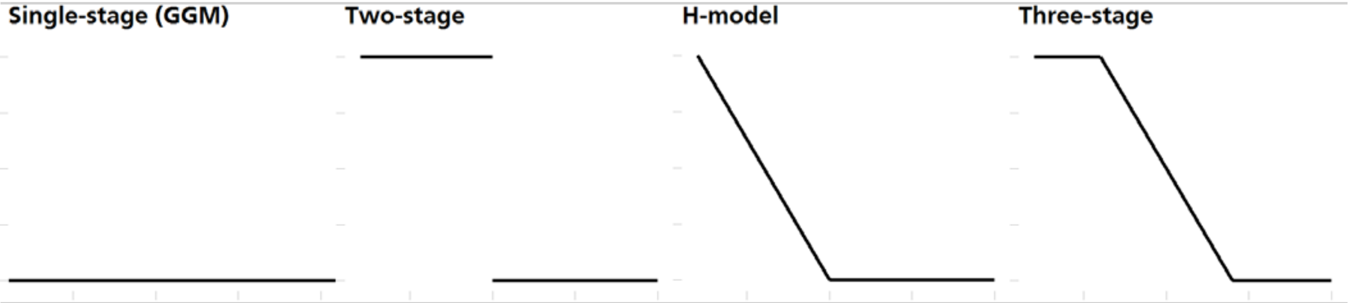
Extending to multi-stage

"Everything should be made as simple as possible, but no simpler" – Albert Einstein

Evidently the rigidity of the assumptions in the Gordon Growth Model can become untenable when a company is experiencing an initial high-growth phase. Often a 2-stage, H-model, or 3-stage discount model are used to address this (Figure 7).

Multi-stage models are more flexible, able to accommodate different business phases

Figure 7: Common growth profiles of discount models



Source: UBS Quant

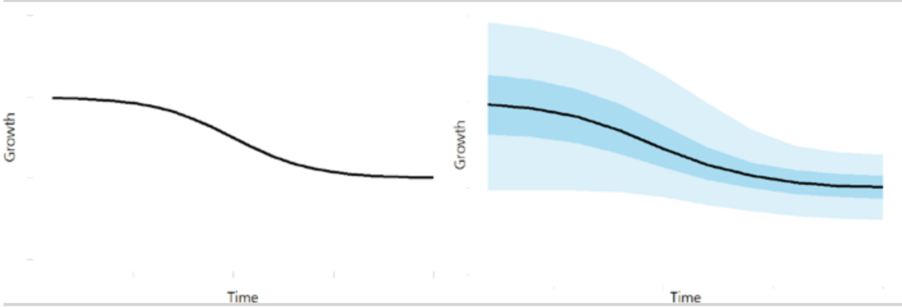
However this just replaces the untenable assumption with more questionable ones; at which points in time should these phases begin and end? Such assumptions will drastically influence the output but often have little to no fundamental insights—to say nothing of the increased uncertainty in now estimating two growth levels.

This replaces an untenable assumption with more questionable ones

Instead, we describe the uncertainty of this transition by parametrising the growth profile of the company using an inverted sigmoid (Figure 8, left), then accounting for the inherent uncertainty in these parameters (Figure 8, right). Not only is this aesthetically pleasing and a parsimonious representation, it more closely represents how we might expect the growth to transition in practice. Shown in light blue are the 10/90th percentiles, dark blue are the 25/75th percentiles, and shown in black is the median of the posterior distribution.

We can parametrise the expected growth trajectory according to our prior knowledge

Figure 8: A smooth and probabilistic representation of a growth profile

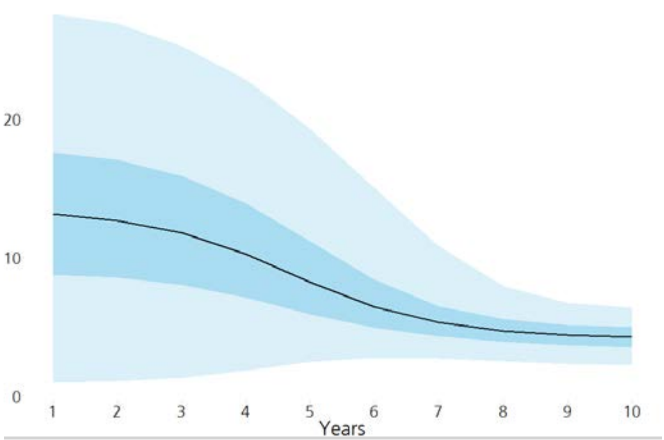


Source: UBS Quant

We can also observe the corresponding uncertainty of the dividend stream as it accretes to its terminal value; which provides a trajectory to which we can calibrate our expectations (Figure 10). Somewhat paradoxically the growth profile exhibits more certainty further into the future, but this is an explicit feature of the model as we assume the cash flows stabilise; converging to the terminal growth rate we define as long-run average GDP growth.

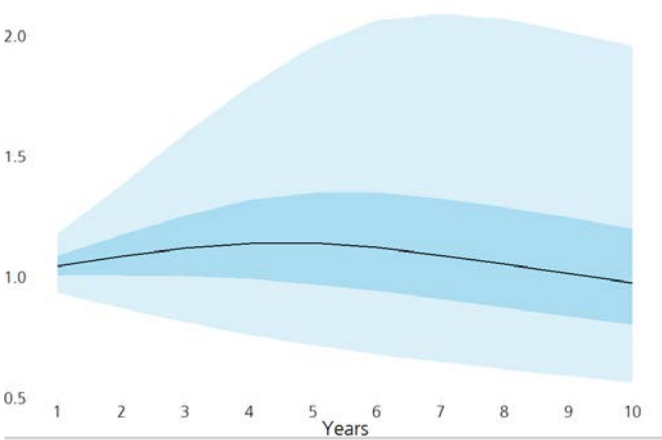
The variance in growth is assumed to shrink as the company matures

Figure 9: Growth profile in practice



Source: UBS Quant

Figure 10: The corresponding discounted dividend stream



Source: UBS Quant

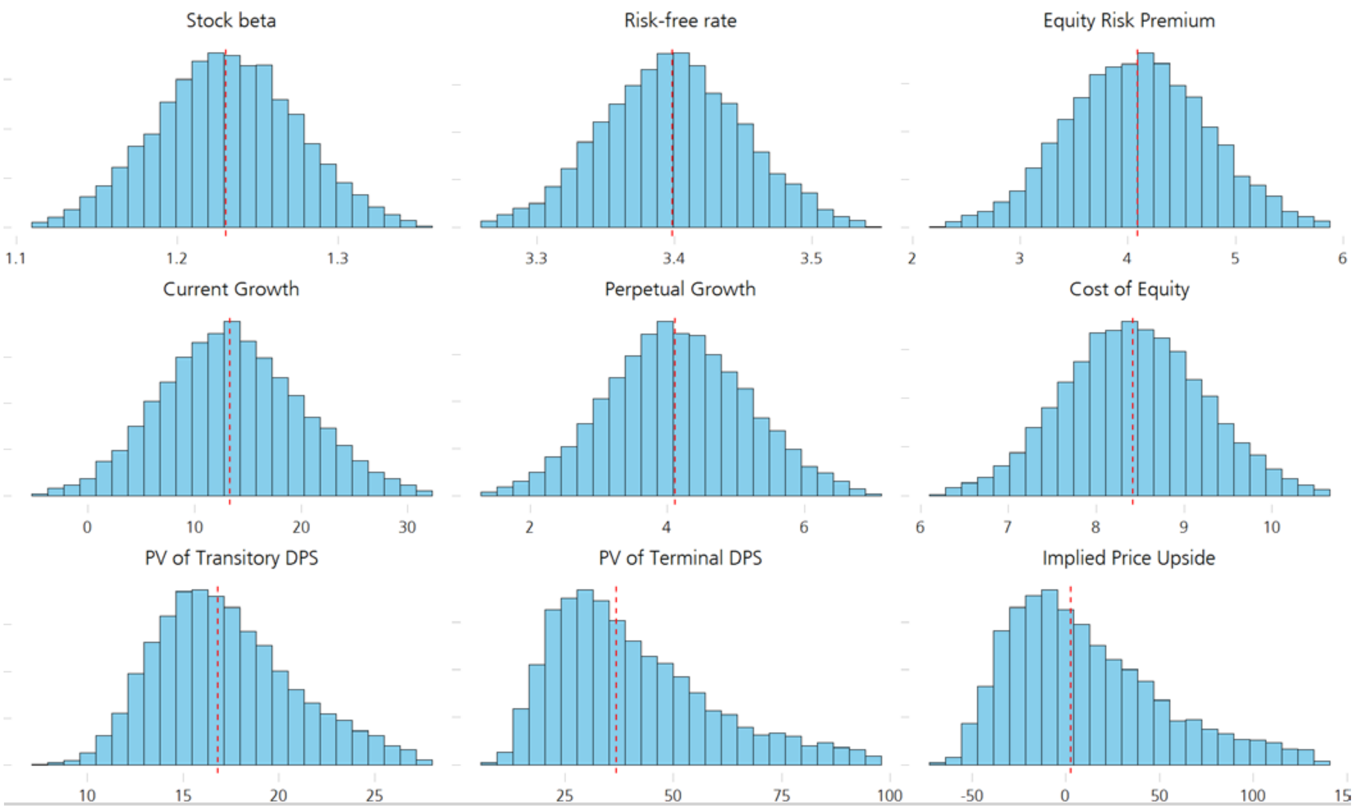
The output of what is effectively an infinite-stage discount model is shown below in Figure 11. We can see that the variance in the implied price upside has collapsed dramatically, primarily due to the reduction in variance of the expected perpetual growth rate. Shown in vertical dashed lines are the medians of the distributions.

The variance in the upside has reduced as a result of the improved model

Further, the median of this forecast distribution is roughly 0%; indicating that our estimate of equity value is calibrated to consensus market expectations. This is not necessarily the criteria by which we should evaluate the success of our model, but it does lend credibility to the functional form of our discount model and the subsequent result.

This result also appears to be calibrated to market expectations

Figure 11: The output of the infinite-stage discount model



Source: UBS Quant

We can now observe that our implied price upside contains significant probability mass before zero; while our earlier estimates ranged from 3.5% to 50% to 120% as our modelling progressed through the steps above, the median price upside is now just 6%—this stock appears fairly priced *at best*, with a reasonable chance of an investor taking a haircut on the basis of this valuation.

Our final model indicates that the stock is actually fairly priced at best—compared to the large discount we saw earlier

In Figure 11 we define the transitory period as twice the midpoint of the sigmoid, which is one of the few parameters that cannot be meaningfully systematised; the high growth period is typically assumed to decline once any barriers to entry have subsided, eg, perhaps a patent expires, a tariff is enacted or regulatory change is expected to take effect, a new technology comes to market, etc.

Building out complexity

Further yet, we can incorporate any accounting identities as necessary (eg, the relationship between margins and ROE); any economic expectations (eg, risk-free rates according to central bank targets, inflation implied from the breakeven rate); any time-series modelling, or indeed any other quantifiable forward-looking views (eg, an ex-ante estimate of the equity risk premium).

This approach is infinitely flexible, not constrained by assumptions of, for example, Gaussian innovations or fixed parameters

In subsequent reports we may continue to refine this model, incorporating domain knowledge from different disciplines (equity strategy, economics, and obviously the sector analysts); elaborate on the accounting (eg, generalising the model to cash flows to the firm); include different asset classes (eg, we could estimate the cost of debt as a floor for the cost of equity); and of course we could adopt a more refined definition for the cost of equity, using an alternative (and empirically more successful) pricing model to the CAPM.

Providing a framework for combining multidisciplinary insights

We believe this is fertile ground for combining quant, fundamentals, accounting, and economics in a structured manner with directly useful and relevant outputs.

Completely transparent with directly relevant outputs

Beyond a sensitivity analysis

This approach could crudely be considered a sensitivity analysis on steroids, the value of which is perhaps more familiar. However if an investor were to simply loop through the potential parameter values as per a traditional sensitivity analysis, we anticipate several problems:

- Crucially, this does not account for any interaction between the variables of interest, when in fact these parameters are rarely independent and are even related through well-understood mechanisms, eg, the relationship between ROE and gearing, or GDP growth and the risk-free rate.

Interaction between variables is crucial to accommodate

- All parameter values in a traditional sensitivity analysis are assumed to be equally likely, which is objectively false. Instead we are accounting for a reasonable distribution of the parameters via specification of the priors and an economic model via specification of the likelihood.

Parameters are not equally likely; some have hard constraints

- The universe will die of a heat-death before the simulation ever finishes. Not shown in Figure 11 are the dozens of other parameters in the model, in addition to the hundreds of parameters within the timeseries models. A method of Bayesian computation called grid approximation takes a similar approach—it is completely impractical for all but the smallest models.

Conventional sensitivity analyses do not scale well

Modelling the investment horizon

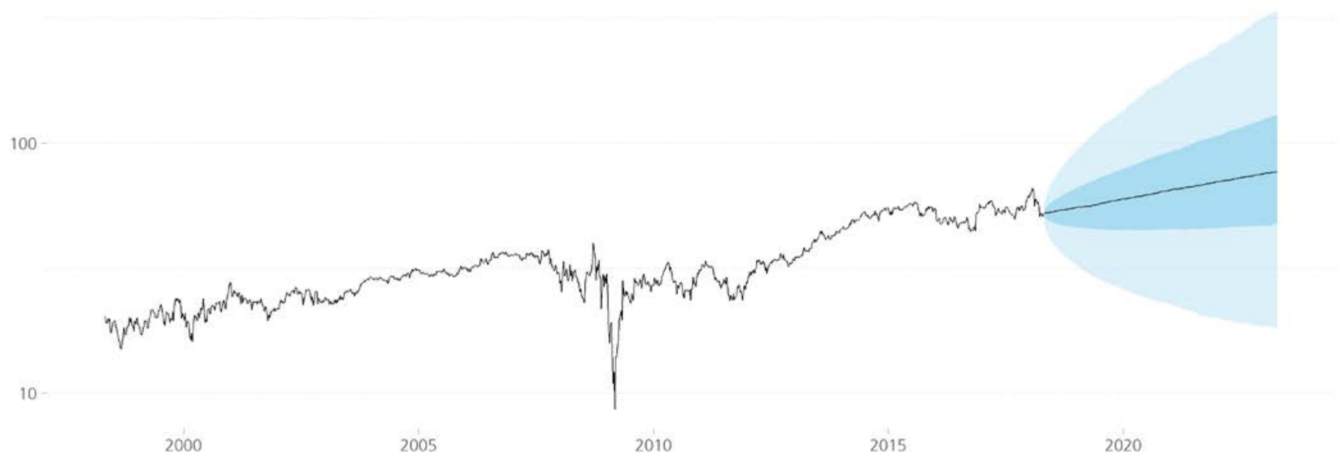
The valuation distribution is relatively static as it has no explicit dependence on the market price; rather it just reflects the present value of all future dividends. Thus it only updates with each successive dividend that turns ex, or when expectations of the cost of equity or economic conditions change—it represents the equilibrium of these inputs.

The valuation distribution is relatively static and independent of the market price

However we can also model our expectations of the stock price using a timeseries model derived from the stock price alone, which captures the price volatility or any trending behaviour in the stock price, as shown in Figure 12. Unlike the valuation distribution the variance of this stock price widens over time, as the uncertainties compound in the absence of an equilibrium condition as in the valuation model.

The absence of an equilibrium condition in the price forecast makes the uncertainty compound

Figure 12: The timeseries model forecast

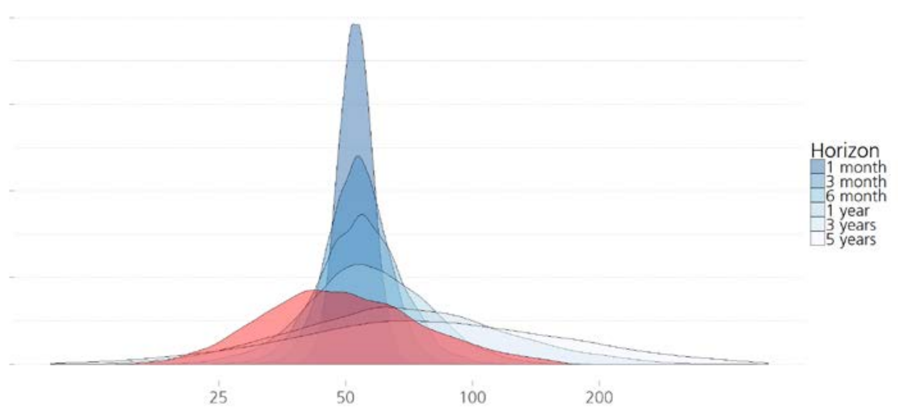


Source: UBS Quant

This provides a useful contrast between where our expectations of the fair value lie and which path we can expect the stock price to take to converge to this value. In Figure 13 we show the forecast price densities with the valuation overlaid in red.

The contrast is useful to understand market expectations

Figure 13: The price forecasts collapse as the forecast horizon extends



Source: UBS Quant

The intuition is clear: to forecast the stock price tomorrow we are obviously much better served using our timeseries model; however this becomes meaningless as we extend the forecast far into the future—after some critical point we are better served using our valuation model instead.

The price distribution becomes less reliable than the valuation distribution at some point

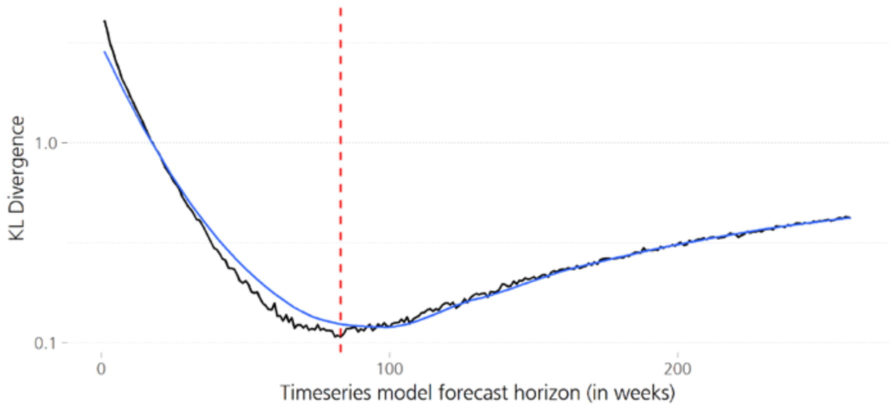
We can actually quantify this concept using the Kullback-Leibler (KL) divergence[3], which features extensively throughout statistics and machine learning. This simple calculation essentially measures how much one probability distribution differs from another one; more abstractly it describes the information change when the price forecast is used to approximate the valuation forecast.

The Kullback-Leibler divergence is a measure of how much one probability distribution differs from another

Figure 14 now shows the KL divergence as a function of the price forecast horizon, in which we observe a minimum at roughly 80 weeks. This means the information in the valuation forecast is closest to the 80-week forecast of the stock price[4]. Prior to 80 weeks the price forecast contains more information; after 80 weeks we can expect our valuation model to be a more precise forecast.

We can estimate the time at which the price forecast becomes more informative

Figure 14: KL divergence of the price vs valuation forecast



Source: UBS Quant

In practical terms this might reflect the investment horizon that this valuation thesis is expected to take effect over. An extremely precise valuation might be matched in price uncertainty to six months away; which suggests that the market would price this outcome much more quickly thus the deviations from fair value would exhibit much faster mean reversion.

This reflects the investment horizon that this valuation thesis is expected to take effect over

Of course, this depends on the correct specification of the valuation model and the timeseries model. It should not be taken for granted that there are many possible specifications of these models which might be appropriate for the task at hand.

Conclusion

The biggest opportunity here is not necessarily the incorporation of this data into a purely systematic process; rather this appears as fruitful ground for bridging the divide between the quant and fundamental investment approaches.

Bridging the divide between quant and fundamental investment approaches

Nonetheless for systematic managers, the quantifiable range of outcomes is just as interesting. The value here in accounting for uncertainty at the fundamental level means that risk can be managed, scenarios can be priced, turnover can be limited, and idiosyncratic risk identified at a resolution that is impossible with conventional approaches. In subsequent research we intend to explore these opportunities in greater detail.

[3] The KL divergence for continuous distributions is $D_{KL}(P||Q) = \int_{-\infty}^{\infty} p(x) log \frac{p(x)}{q(x)} dx$

[4] This is similar notion to the moment projection of the price distribution onto the valuation distribution, i.e. we are interested in $t_0 = \arg\min_{t \in T} D_{KL}(q||p_t)$, in which p_t represents the price forecast distribution at horizon t and q is the valuation distribution

Appendix

We built the model using Stan, a state-of-the-art platform for conducting statistical inference; however there are alternative frameworks available (OpenBUGS, JAGS, PyMC3 and Edward are under active development). The model design is as follows.

Firstly we estimate our CAPM beta with a simple linear regression. We adopt a highly informative prior on the alpha and beta given the nature of the companies to which the DDM is applied and assume Gaussian noise centred at zero with a standard deviation described by a half-normal Gaussian.

$$r_{s,t} - r_{f,t} = \beta \cdot (r_{m,t} - r_{f,t}) + \alpha + \varepsilon$$

$$\alpha \sim N(0, 0.2^2)$$

$$\beta \sim N(1, 0.1^2)$$

$$\varepsilon \sim N(0, \sigma^2)$$

$$\sigma \sim N^+(5, 2^2)$$

We adopt a constant-mean model of the risk-free rate for simplicity. Obviously this can be improved using an ex-ante view of the credit cycle from which we can draw on slow-moving economic data as necessary.

$$r_{f,t} = \mu_{rf} + \varepsilon_{f,t}$$

$$\mu_{rf} \sim N(2.5, 0.5^2)$$

$$\varepsilon_{f,t} \sim N(0, 2^2)$$

We model annual GDP growth in a similar fashion; nominal growth centred at a constant mean, but given the extensive history and low-frequency nature of this data we also accommodate the fat tails arising from economic recessions using a Cauchy distribution. As above, this does not account for the autocorrelation in the residuals; however in the absence of predictable components in the timeseries (like seasonality or trend), this simple form yields surprisingly competitive forecasts.

$$gdp_t = \mu_{gdp} + \zeta_{\mathrm{t}}$$

$$\mu_{gdp} \sim N(4, 0.5^2)$$

$$\zeta_{\mathrm{t}} \sim C(0, \gamma_{\mathrm{gdp}})$$

$$\gamma_{gdp} \sim N^+(1, 0.5^2)$$

We simply define the equity risk premium as the difference of the long-term mean annual equity market growth rate and the mean risk-free rate. As above we could adopt any more refined ex-ante estimate of the equity risk premium or any time-varying view as desired. Another refinement is accounting for the correlated nature of these innovations; growth, the risk-free rate, and the equity market returns are obviously not independent. The tilde below denotes the annualised market return; all returns are scaled to percentage terms.

$$\tilde{r}_{m,t} = \mu_m + \xi_t$$

$$\xi_t \sim C(0, 5)$$

$$\mu_m \sim N(8, 1)$$

$$r_e = \mu_m - \mu_{rf}$$

$$k_e = \mu_{rf} + \beta \cdot r_e$$

The dividend stream is modelled via a structural timeseries representation, whose dividends are observed with some error σ_o (this might correspond to the difference between the potential versus paid cash dividends), around level u_t with innovations $\eta_{u,t}$ (which might correspond to variance in the dividend policy set by management), and a stochastic drift component with deviations from its long-term growth rate G according to an AR(1) process with autoregressive coefficient ρ, which we restrict as stationary by imposing a boundary-avoiding prior. We set an informative prior G_0 as the annual growth that the analyst believes is reasonable, or alternatively we could define this by industry growth in the context of a hierarchical sector model. The parameter f is fixed and describes the underlying frequency of the dividend growth stream (this is quarterly=4, in our example above).

$$\log(dps_t) \sim N(u_t, \sigma_o^2)$$

$$u_t = u_{t-1} + v_{t-1} + \eta_{u,t}$$

$$v_t = G + \rho(v_{t-1} - G) + \eta_{v,t}$$

$$\eta_{o,t} \sim \Gamma(2, 100)$$

$$\eta_{u,t} \sim \Gamma(2, 100)$$

$$\eta_{v,t} \sim N(0.05, 0.01^2)$$

$$\tfrac{1}{2}(\rho + 1) \sim Beta(2,2)$$

$$G \sim N(\log(1 + G_0 f^{-1}), 0.01^2)$$

Once we have the pieces in place as above, we can simply estimate our valuation using the following relations. We use the sigmoid function to transition the growth profile from transitory to terminal, incorporating exogenous parameters T_k and T_0 which determine the period and rate at which this is expected to take place.

$$G_{st} = \exp(fG) - 1$$

$$G_{lt} = \mathrm{N}\left(\mu_{\mathrm{gdp}}, \gamma_{gdp}^2\right)$$

$$g_t = G_{st} + \frac{(G_{lt} - G_{st})}{1 + \exp\{-t_k \cdot (t - t_0)\}}$$

$$t_0 \sim N(T_0, 1)$$

$$t_k \sim N(1, T_k)$$

$$d_t = dps_0 \prod_{i=1}^{t} \left(\frac{1 + g_i}{1 + k_e}\right)$$

$$V_{trans} = \sum_{t=1}^{2T_0} d_t$$

$$V_{term.} = d_{2T_0} \cdot \frac{1 + G_{lt}}{k_e - G_{lt}}$$

$$upside = 100 \cdot \left(\frac{V_{tran.} + V_{term.}}{market\ price} - 1\right)$$

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Buy	FSR is > 6% above the MRA.	46%	25%
Neutral	FSR is between -6% and 6% of the MRA.	39%	23%
Sell	FSR is > 6% below the MRA.	15%	12%
Short-Term Rating	**Definition**	**Coverage[3]**	**IB Services[4]**
Buy	Stock price expected to rise within three months from the time the rating was assigned because of a specific catalyst or event.	<1%	<1%
Sell	Stock price expected to fall within three months from the time the rating was assigned because of a specific catalyst or event.	<1%	<1%

Source: UBS. Rating allocations are as of 31 March 2018.
1:Percentage of companies under coverage globally within the 12-month rating category.
2:Percentage of companies within the 12-month rating category for which investment banking (IB) services were provided within the past 12 months.
3:Percentage of companies under coverage globally within the Short-Term rating category.
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KEY DEFINITIONS:Forecast Stock Return (FSR) is defined as expected percentage price appreciation plus gross dividend yield over the next 12 months. In some cases, this yield may be based on accrued dividends. **Market Return Assumption (MRA)** is defined as the one-year local market interest rate plus 5% (a proxy for, and not a forecast of, the equity risk premium). **Under Review (UR)** Stocks may be flagged as UR by the analyst, indicating that the stock's price target and/or rating are subject to possible change in the near term, usually in response to an event that may affect the investment case or valuation. **Short-Term Ratings** reflect the expected near-term (up to three months) performance of the stock and do not reflect any change in the fundamental view or investment case. **Equity Price Targets** have an investment horizon of 12 months.

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