Concave drilling curve

Name: Kristin Helen Roll and Petter Osmundsen
Address: Dept of industrial economics and risk management, University of Stavanger, NO-4036 Stavanger, Norway.
E-mail: Kristin.h.roll@uis.no and Petter.Osmundsen@uis.no

(1) Overview

In this study we analyse the effect of drilling depth on meter per day (m/d). Since the trend is to drill deeper wells, much focus is on drilling challenges in high temperature high pressure wells (HTHP). This often occurs around 4000 metres drilling depth. Our sample well depth from the primary mid water Norwegian continental shelf is on average almost 3000 meters, ranging from a minimum of 109 to a maximum of 5717 meters, with a standard deviation of 1091 metres. Thus, drilling depth is relatively homogeneous and there are just a few HTHP wells in our sample. Nevertheless, drilling depth plays a vital role.

(2) Methods

In Figure 1, m/d - measured as average meter drilled per day - is plotted against the depth measure. The dots show average m/d for the sample wells, and the red line shows a line fitted to these points. As illustrated by the figure, m/d increases until it reaches a peak around 3000 meters and then gradually falls again. There are several factors that contribute to the increases with well depth. For example, it takes time before proper return of liquids is established. When this is in place, salt water can be replaced by drilling mud, and m/d picks up.

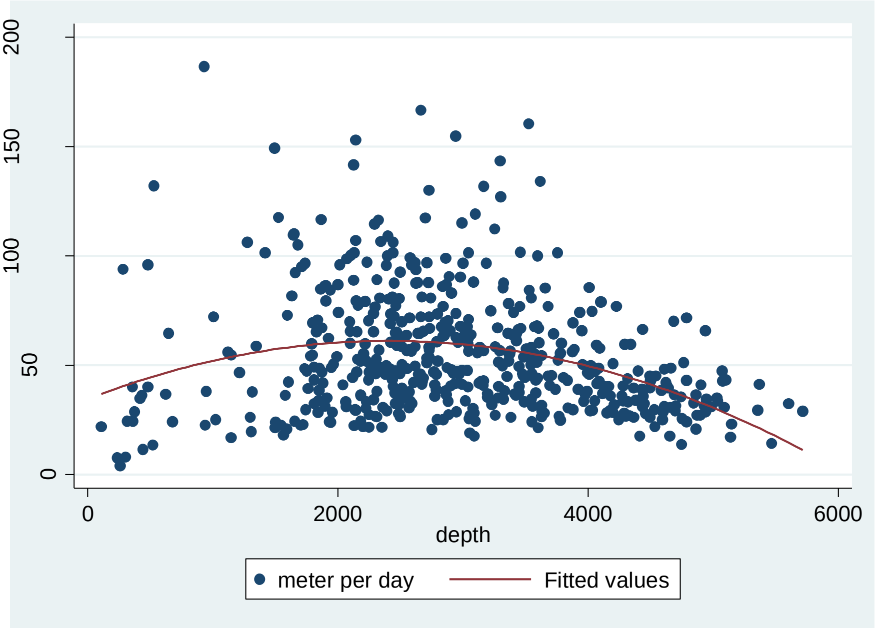

Fig. 1: m/d (average meter drilled per day) plotted against drilling depth, for exploration wells on the Norwegian continental shelf, in the period 1965-2008. Data source: Norwegian Petroleum Directory.

The decline in m/d can be explained by increasing temperature and formation density as the well depth increases. In other words, as the well is getting deeper, the positive effect is being offset by the negative effects. The positive effects dominate up to approximately 3000 meter. After this point the negative effects dominate.

To isolate the main effects that improve and reduce m/d, we establish a multivariate model of m/d. The model is on a general form is given by:

$$\ln(m/d) = \beta_0 + \beta_{depth} \ln Depth + \beta_{density} \ln Density + \beta_{120} Hightemp$$
$$+ \sum_f \beta_f Tech_f + \beta_{purpose} Purpose + \beta_{trend} Trend$$

where the dependent variable, *m/d,* is average drilled meters per day. The *Depth* variable represents the well depth in meters measured from the sea bottom, while the *Density* variable represents the litostatic pressure measured by the maximum density of the drilling fluid, and *Hightemp* a dummy variable that is one if the bottom hole temperature exceeds 120 degree Celsius. Density and temperature are examples of factors that increase with drilling depth and are expected to slow down m/d. Differences in drilling technology are accounted of by including dummy variables (*Tech*), and we control for the *purpose* of drilling by including a dummy variable that is one if the well is a wildcat and zero if the well is an appraisal well. Finally, a time-trend variable *Trend* is included to control for unobserved technological change.

(3) Results/ Conclusions

Except for the variables that control for different drilling technologies, all parameters are significant at 5% level, indicating that they are important in explaining m/d. We find a positive average time trend of 1.6 per cent that accounts for technological development. Appraisal wells have lower m/d than wildcats due to more time spent on testing. As expected both density and temperature are found to have a negative effect on m/d. Increasing the density by one per cent will one average reduce the m/d by 1.1 per cent and as temperature exceeds 120 degree Celsius the m/d decrease additionally 0.23 per cent.The effect depth has on m/d is one of the main findings in this paper. A 1% increase in well depth leads to a 0.38% increase in m/d, everything else kept equal. In other words, with the parameters for density and temperature are capturing the negative effect, the parameter for drilling depth now captures the positive effects, i.e., the effect of depth for a given temperature and density. This accounts, e.g., for the fact that high weighting agents and optimal torque increases m/d as drilling gets deeper.