The Depletion Paradox

Excerpt from Third Quarter Natural Resource Market Commentary
Goehring & Rozencwajg: Natural Resource Investors
December 5, 2024
https://blog.gorozen.com/blog/the-depletion-paradox

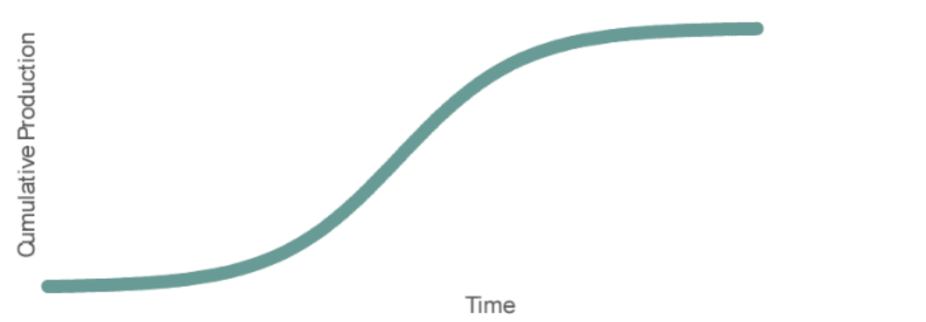
-G&R have been expecting for some time a peak in US shale oil and gas production
-it appears to have arrived (Nov. 2023) about a year earlier than they had predicted (late-2024/early-2025)
-since last fall oil production has slid 2% and gas production 1%, and G&R models envision this decline to accelerate
-most view this with skepticism countering that the slowdown is simply a pause (due to low prices and regulation constraints) and that the incoming US administration and higher prices will restart production growth
-"The primary forces behind the current downturn are neither policy-related nor purely economic—they are geological and inexorable. Depletion, not market dynamics or regulatory overreach, is the central culprit." (p. 7)
-it is likely increased drilling will be encouraged, but this cannot counter geologically-determined production declines
-G&R blend Hubbert's initial modelling/analysis with neural networks and artificial intelligence to fine-tune models and apply it to shale production, providing novel insight

-few in the industry accept the implications of the proposed production trajectory, arguing that higher prices will encourage drilling of less productive lands
-G&R, however, contend that the decline is structural in nature
-"Our models point to a sobering conclusion: even with substantially higher prices and an abundance of undrilled locations, production is set to continue its decline. We call this phenomenon the "depletion paradox." It is a familiar story, and history provides a clear precedent." (p. 8)
-conventional crude oil production in the US peaked in 1970 and the first OPEC 'crisis' occurred in 1973
-these prompted the US government to expedite permitting via deregulation
-optimism of an oil/gas boom ensued
-despite the price soaring ($3.18 per barrel in 1973 to $34 per barrel in 1981) and rig count climbing (993 in 1973 to 4500 in 1981), production continued to decline
-by 2010, when the price was around $100 per barrel, the decline was still in motion
-a depletion paradox was firmly entrenched and the assumption that prices would counter geology failed

-history seems to be repeating with respect to the US shale industry
-"The lessons of history are clear: enthusiasm for growth, however well-intentioned, cannot override the fundamental constraints of geology. And if we fail to heed these lessons, we risk not just disappointment, but the stark realization that higher prices and bold policy initiatives are no match for depletion's steady advance." (p. 9)

<u>King Hubbert–A History</u>
-a geologist for Shell, Marion King Hubbert predicted in 1956 that the US conventional oil production would peak in 1970
-to most at the time this seemed completely implausible, especially given the previous century's growth
-it occurred, however, precisely when he had suggested
-Hubbert's argument was based upon the fact that every hydrocarbon basin was finite in nature and cumulative production would thus follow a predictable trajectory over time: beginning at zero, extraction would rise (the steepness of the rise depending upon the speed of extraction) until it hit the upper boundary of production
-to approximate the growth curve, Hubbert proposed the use of a logistic curve as seen in Figure 1

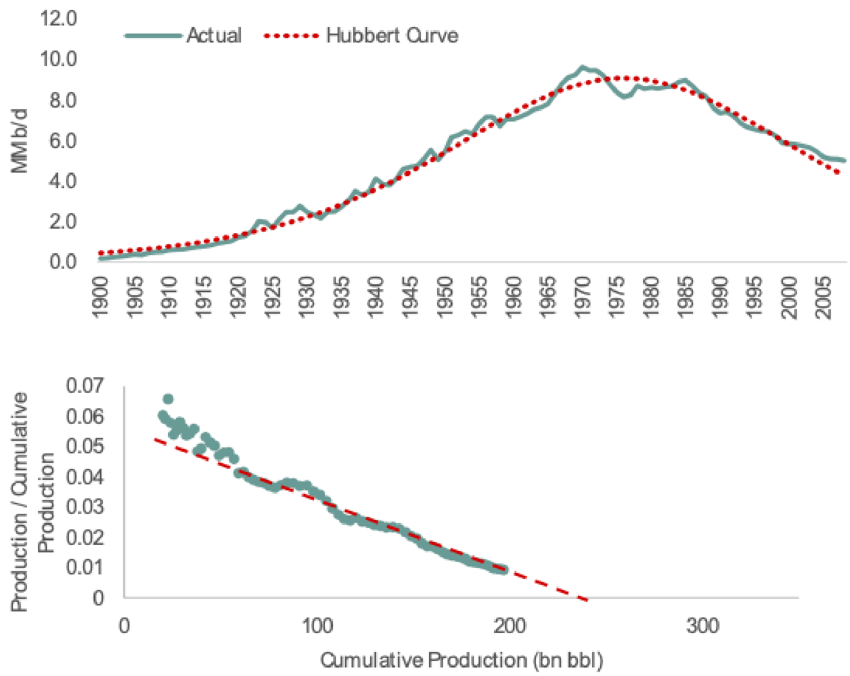
FIGURE 1 Cumulative Production Over Time



Source: G&R.

-a more bell-shaped curve (aka Hubbert's Curve) is created when using a derivative of the cumulative production vs time
-Hubbert also introduced 'linearization' "By plotting the ratio of annual production to cumulative production (P/Q) against cumulative production (Q)" (p. 10)
-this relationship showed a straight line shortly after an initial period of variability; this line could be extrapolated to estimate ultimate recoverable reserves and a production profile coefficient (See Figure 2)
-using these data, a Hubbert Curve could be created that provided the magnitude and timing on a basin's peak

FIGURE 2 Hubbert Curve & Linearization for US Conventional Production



Source: EIA and G&R.

-a key insight for Hubbert's model was that a basin typically peaked at a point close to 50% of a basin's reserve

-it appears that production stops growing at this point due to depletion and production dynamics

-decline is inevitable despite significant resources remaining–thus the term 'depletion paradox'

<u>Explaining Hubbert–From Macro To Micro</u>

-the logistic curve is powerfully predictive yet one of its major criticisms is because no one understood why (even Hubbert)

-higher prices and new technology should override limits for the most part, but history has shown this is not so

-if we shift from a macro view (entire basin) to a micro one (individual well) the picture becomes clearer

-every new well added to a basin's in the early phase of extraction adds to total production, but as each individual well comes online its production begins to decline in a predictive way

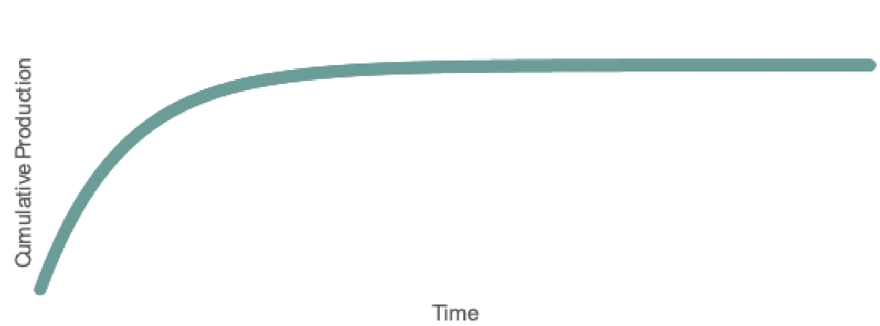
-as new wells are brought online, the cumulative growth is impacted by increasing decline of older wells

-overall output will only continue to grow if new well production exceeds older well decline

-as time passes, the base decline increases

-at some point a balance of growth and decline occurs and cumulative production levels off (see Figure 3)

FIGURE 3 Unlimited Identical Wells Drilled Constantly



Source: G&R.

-this is why depletion constraints cannot be overcome by investment and new technology, even were there infinite potential

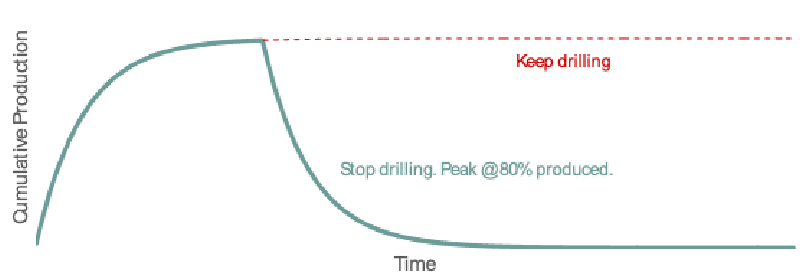
-"It underscores a fundamental truth: growth is bound not just by resources but by the interplay between new additions and inevitable declines. Higher prices and technological advancements may influence the pace, but they can't alter the underlying dynamics that eventually lead to a plateau in production." (p. 12)

-a basin does not have infinite potential, however, so the production profile of a basic with finite potential is different

-basins experience a surge in growth early on as new wells come online, reach a plateau, and then decline sharply acting nothing like Hubbert's logistic model with the peak occurring later when about 80% of reserves have been extracted (see Figure 4)

-this demonstrates how production is impacted by finite limits; even when production appears robust, depletion is inevitable

FIGURE 4 Fixed Number of Identical Wells Drilled Constantly To Exhaustion



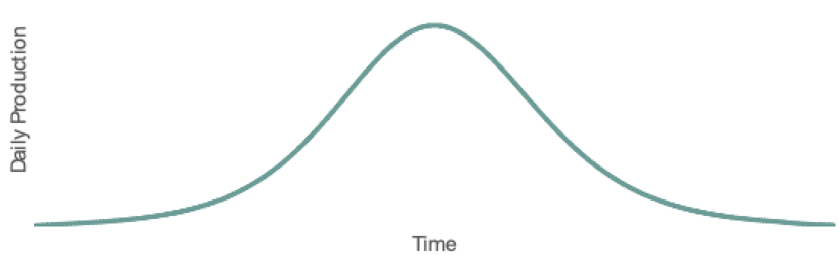
Source: G&R.

<u>More Realistic Examples</u>

-examples thus far have been to illustrate key principle

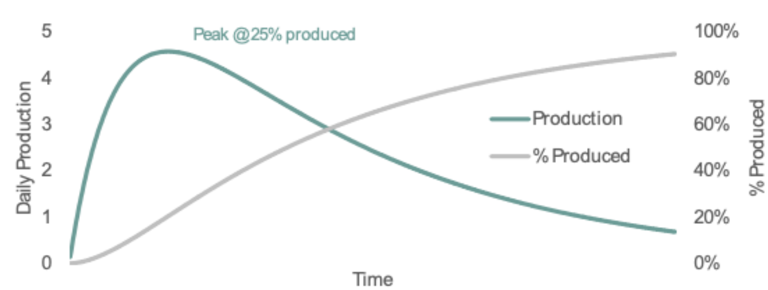
-in reality, extractors are constrained by where and how much to drill
-unproven fields carry uncertainty, so slow and cautious drilling define the early phase
-once potential is realised and cash flow increases, activity is ramped up quickly
-development slows as undrilled areas disappear and a desire to maintain some reserves exists
-drilling rate tends to mirror a bell curve with an acceleration to a peak and then tapering as the field matures
-a classic logistic curve will be followed for production with certain assumptions, with peak occurring at the 50% extraction level and coinciding with a slowing of drilling (see Figure 5)

FIGURE 5 Fixed Number of Identical Wells Drilled With Variable Schedule



-under controlled conditions, this bell curve is how extraction would proceed and highlights the relationship between drilling intensity and resource depletion
-operators tend to drill the best potential areas first both within an individual basin and across a range of basins
-as time passes and the 'sweet spots' are exhausted, per well productivity declines
-assuming infinite wells beset by declining productivity, the extraction trajectory will exhibit growth to a plateau where it rolls over and begins to decline (more slowly than the growth path)
-peak timing, counter-intuitively, depends upon the rate of production decline (e.g., 5% per year decline peaks at 20% of recoverable reserves, 10% per year at 25%) (see Figure 6)

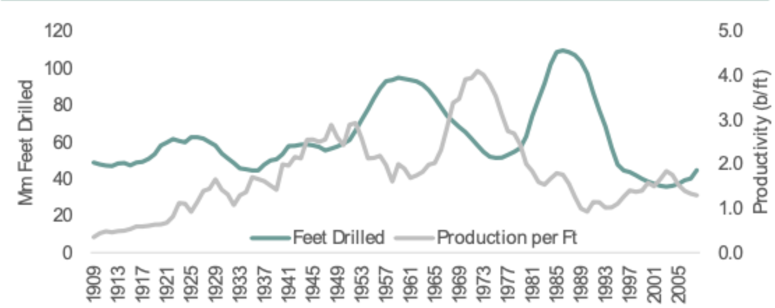
FIGURE 6 Constant Drilling of Wells Whose Productivity Degrades by Year



-there exists a relationship between well quality and drilling schedules, with drilling a pivotal factor in maximising present value
-if drilling is too quick, the best spots are exhausted faster; but slower drilling can extend field life (at delayed return)
-the production profile of a field is dictated by the development strategy taken and resource depletion aspects

Conventional US Production–A Case Study
-US drilling was steady between 1900 and 1945 (about 50 million feet of drilling per year) as production soared with output growing from 0.5 to 3 barrels per foot drilled
-during the 1950s drilling activity increased reaching 100 million feet but productivity fell to 1.5; so, despite a 70% surge in drilling activity, production only increased 20%
-depletion rates also climbed, trimming growth by about one third–a production plateau was imminent
-production quotas and regulations slowed drilling during the 1960s with extraction focusing on the best basins; this led to a doubling of productivity
-as the best areas matured, productivity began falling in 1970; falling by almost 75% by the mid-1980s
-despite a surge in drilling, productivity continued to fall
-drilling and productivity tend to be inversely related (see Figure 7)

FIGURE 7 US Feet Drilled & Productivity



Source: EIA.

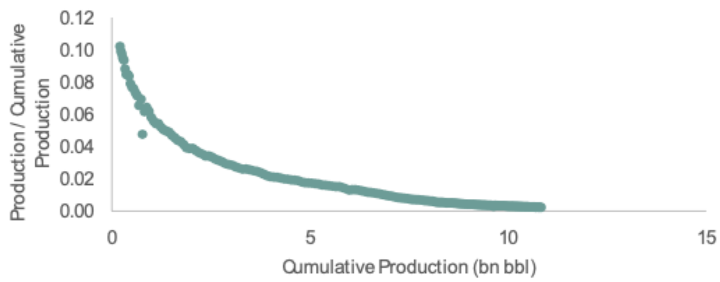
-lots undrilled areas remained, but of much lesser quality

Turning to the Shales
-shale basins differ from conventional ones in that they are more extensive requiring more drilling
-dramatic differences in productivity across a basin occurs, with the best areas producing up to 4 times that of the worst
-well decline tends to play a larger role with earlier peaks and longer tails

-shale plays show a distinct production profile: high extraction rates initially followed by a steep decline and finishing with a prolonged low-rate output–a result of the hydraulic fracturing process

-these unique features cause shale wells to defy Hubbert linearisation, displaying a curve rather than a line (see Figure 8)

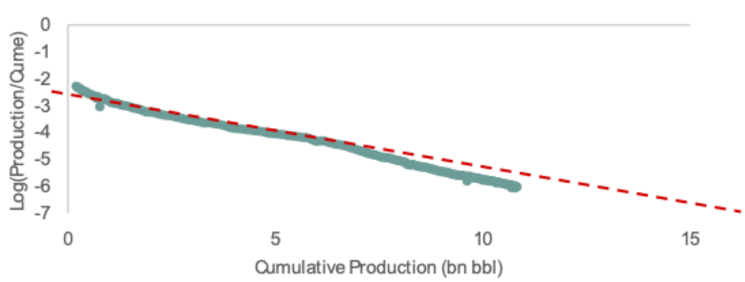
FIGURE 8 Fayetteville Hubbert Linearization



Source: NoviLabs.

-using Hubbert linearisation to predict the productivity of shale basins proved problematic; but this led to the discovery by G&R that the relationship was logarithmic, not linear, and whose extrapolation of productivity was precise (see Figure 9)

FIGURE 9 Fayetteville Logrithmic Hubbert Linearization



Source: NoviLabs.

-this information was used to predict the peak/rollover of a number of major shale basins (e.g., Barnett, Bakken, Eagle Ford, Fayetteville) (see Figure 10a) whose productivity has crashed (26-80% declines)

-a similar analysis of additional shale plays suggests that they have recently begun to decline (e.g., subbasins of Marcellus and Permian) (see Figure 10b)

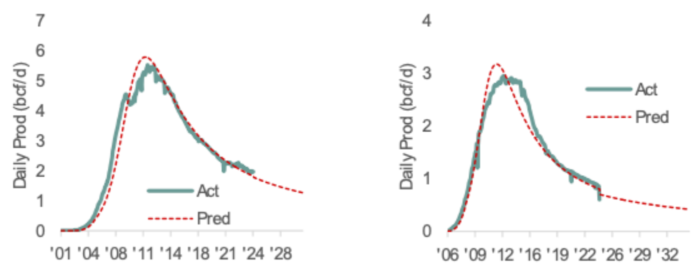
-this logarithmic Hubbert Linearisation (lHL) also shows the longer tail of shale basins

-this tool allows accurate prediction of basin peak, with most peaking when about 30% of their recoverable reserves have been extracted

<u>Enter Neural Networks</u>

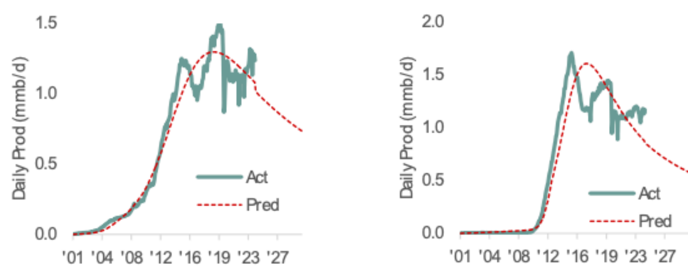
-G&R began developing their own Artificial Intelligence (aka neural network) in 2019 to aid their analysis

FIGURE 10a Barnett and Fayetteville Logrithmic Hubbert Curve



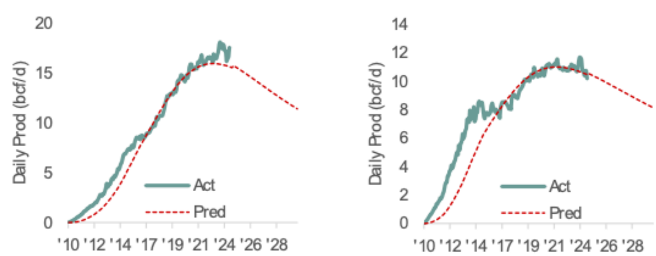
Source:NoviLabs and G&R.

FIGURE 10b Bakken and Eagle FordLogrithmic Hubbert Curve



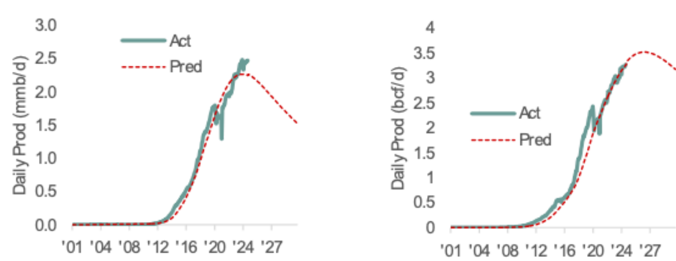
Source:NoviLabs and G&R.

FIGURE 10b SW & NE MarcellusLogrithmic Hubbert Curve



Source:NoviLabs and G&R.

FIGURE 10b Midland & Delaware Permian Logrithmic Hubbert Curve

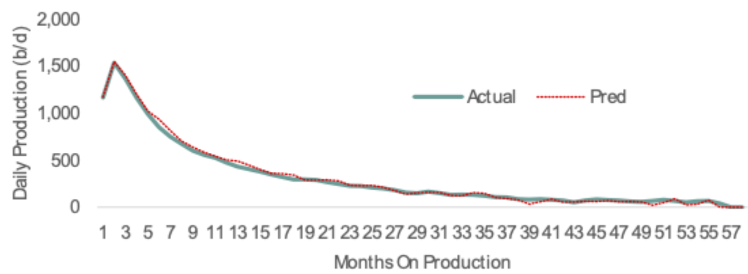


Source:NoviLabs and G&R.

-they customised it for shale production based upon well design, subsurface geology, and regional trends

-predictive curves using this analysis virtually mirror actual production (see Figure 11)

FIGURE 11 Midland Basin Type Curve vs. Actual

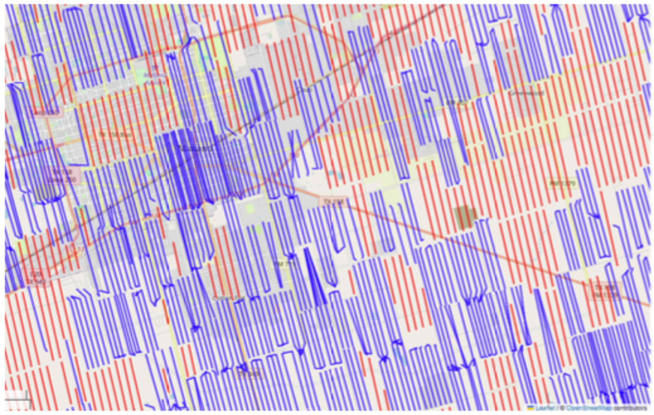


Source:G&R.

-the model has been refined over the years, adding aspects of well design (e.g., lateral length, fluid and propellant loading) and subsurface geology (e.g., clay content, porosity, thermal maturity, pressure, organic content)
-for the Midland side of the Permian Basin, the best spots have been exploited leaving less productive sites; ultimate recoverable reserves were estimated for each well and then aggregated
-the model estimates were within 15% of the lHL estimates and suggest rollover will occur when about 28% of reserves have been extracted
-according to the model, current extraction estimates (28-32% for oil; 30-34% for gas) suggest peak has passed
-"Indeed, total shale oil and gas production likely peaked late last year. Both are already down 1%, and our models predict year-over-year production declines will turn sharply negative within six months." (p. 21)

<u>Depletion Paradox Redux</u>
-the coming decline in production is occurring at a difficult time given that since 2010, global oil demand has been met almost exclusively by shale extraction, helping to suppress US prices by 80% relative to global prices and grow natural gas-fired electricity production and LNG exports
-just as in the 1970s, it is doubtful that surging prices and more drilling will lead to production increases (see Figure 12)
-a majority of today's production is due to relatively recent drilling (60-70% of wells re less than 3 years old) with remaining areas being 35% less productive than wells drilled in 2023
-inferior geology cannot be remediated
-the 1970s saw production plummet despite higher prices and more drilling, and we are likely going to experience the same for shale
-"In the end, the paradox remains—depletion is an unstoppable force, and it is becoming harder and harder to keep up." (p. 22)

FIGURE 12 Drilling Map of Midland County Permian



Source:NoviLabs and G&R.