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Demand-Supply Interactions on Future Mining Resources Production: The Coal Model

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Resource Supply Considerations

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- How much of it exists? (discovery)
- How much is recoverable?
- When is it recovered?
- How fast can it be recovered?

- What market is it supplying?
- What is the demand?
- How long will it last?

What is the interaction between demand and supply with limited resource?

URR – Ultimately Recoverable Resources

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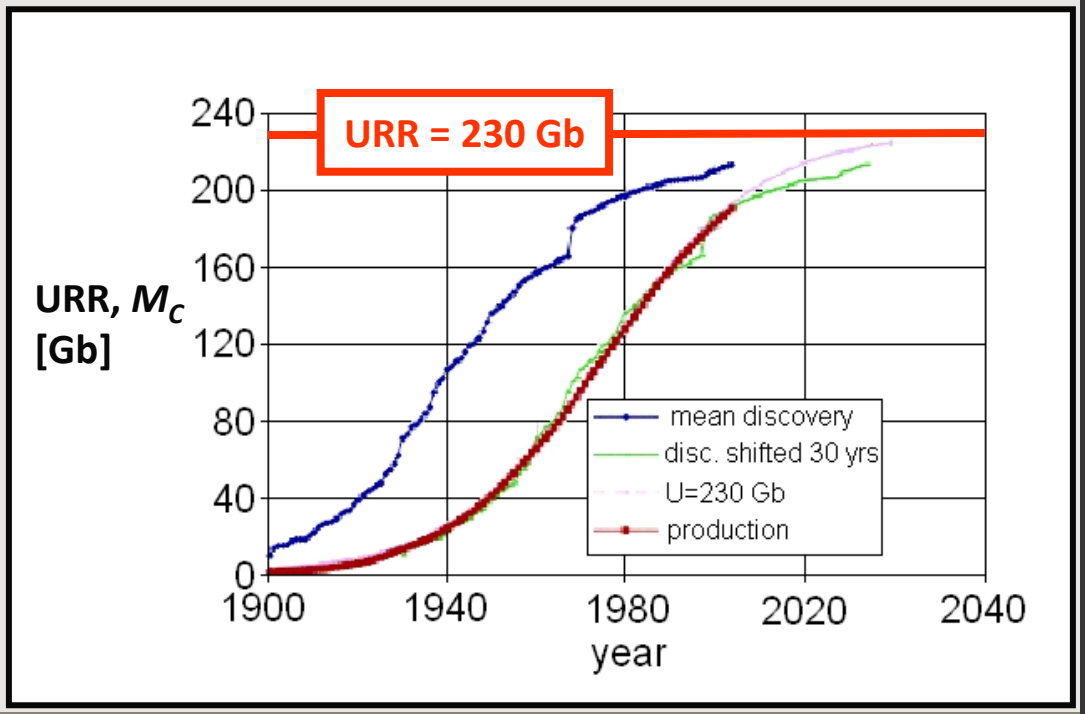
- Total amount of a resource that can be extracted.
- Increase with time as discoveries are made.
- Follows a Sigmoidal curve.

- Example: USA URR and cum. prod., M_C



[1] J Laherrere http://www.mnforsustain.org/oil_forecasting_production_using_discovery_laherrere505.htm (2005)

Annual Production (Hubbert's Curve)

- Annual production assumed to follow a bell curve.
- Given by the gradient of the cumulative production curve:

$$M_S[t] = \frac{dM_C}{dt} = rURR\left[\frac{e^{r(t-t_p)}}{\left(1+e^{r(t-t_p)}\right)^2}\right]$$

r rate constant (y^{-1})

t_p peak year (y)

Deffeyes K. S., 2002. *Oil and Gas Journal* 100(46), p. 46-48.

Does Hubbert's Curve always apply?

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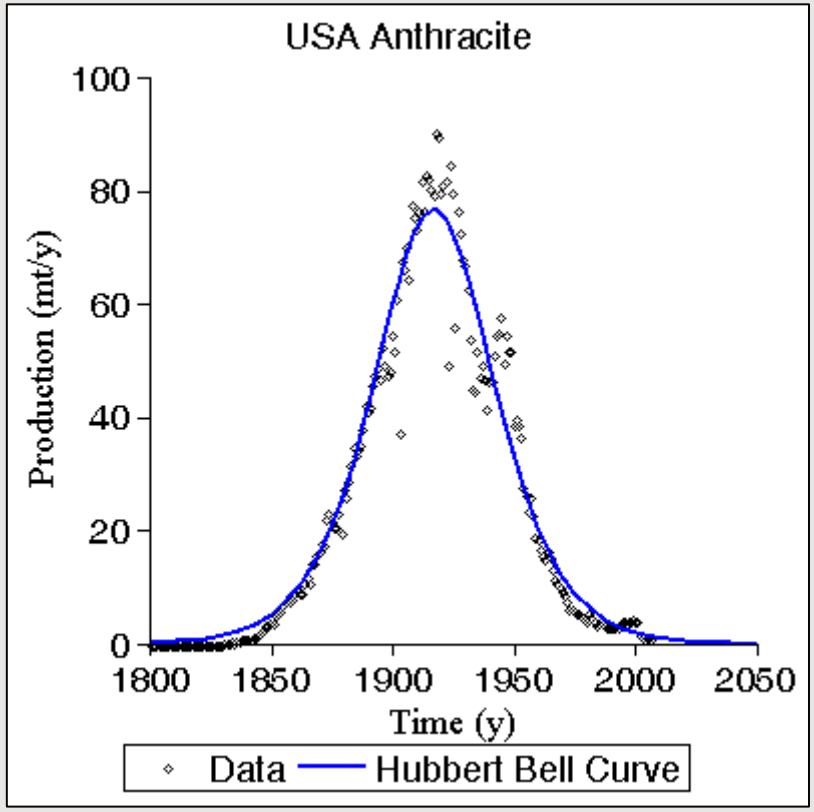
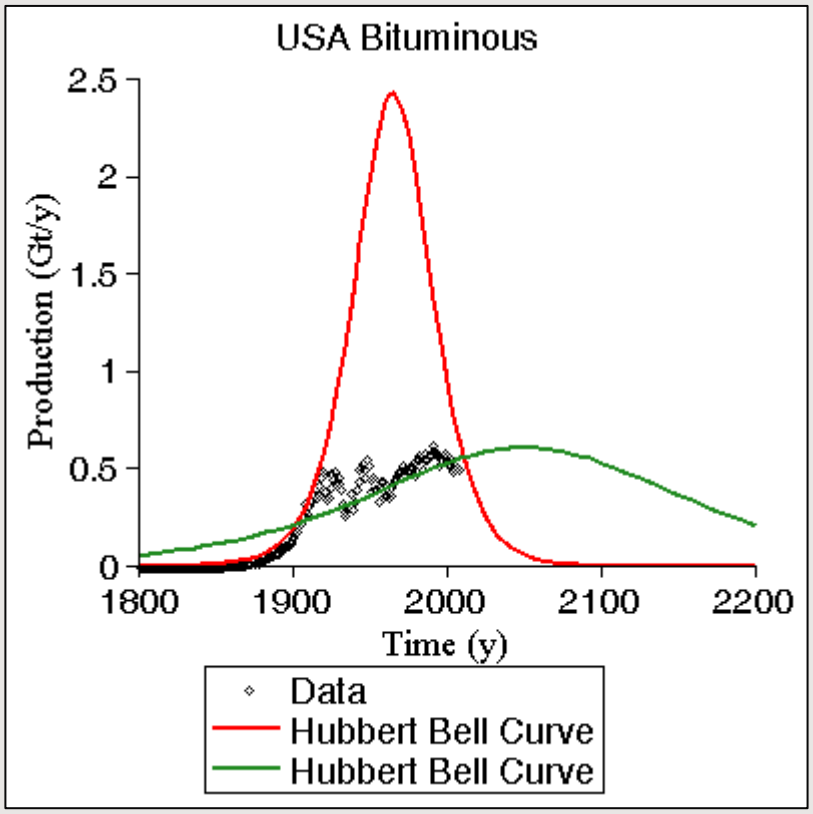
- Both for the USA (anthracite and bituminous).
- Two curves (before and after WW1) for bituminous.





Demand-Supply Model

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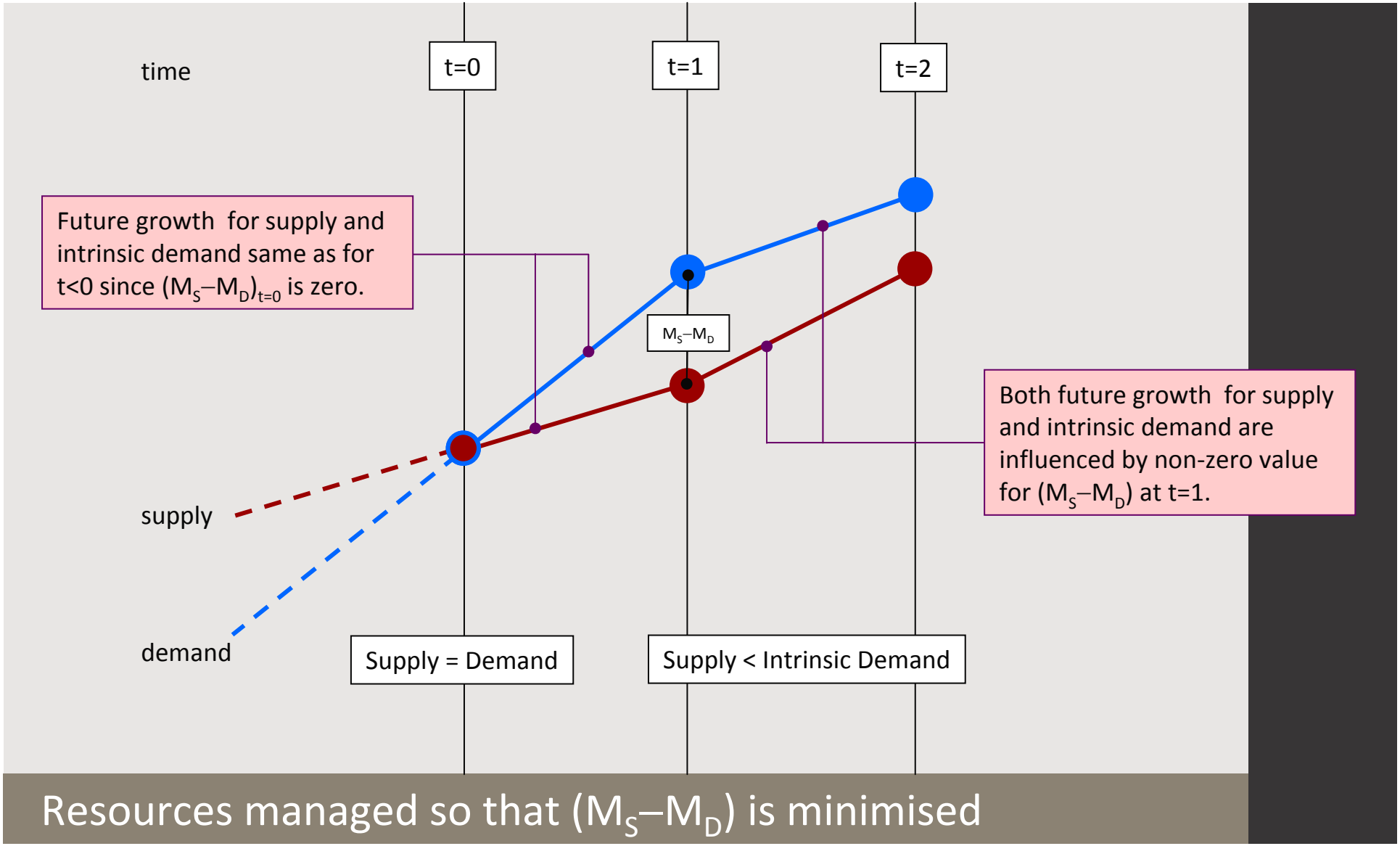
- Based on an identified market for a resource.
- Estimate the URR of the resource for that market.
- Assume production capacity for each operation needed to extract the resource. From URR, gives the total number of operations.
- For each year, operations are brought online, operated at steady state or upgraded, and taken off-line, so that supply meets intrinsic demand.
- If intrinsic demand is greater than supply then intrinsic demand is reduced and supply increased (if capacity allows it) for the following year.

Supply-Demand Interaction



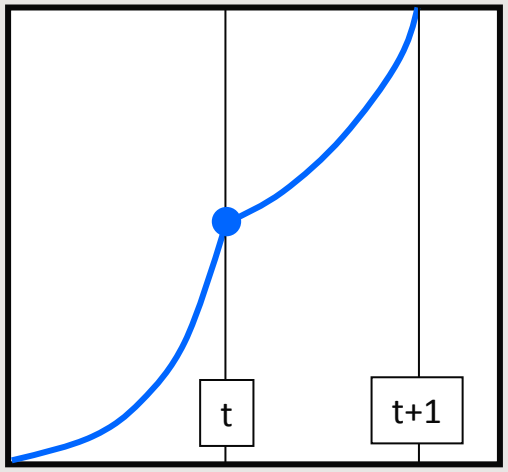
Resources managed so that $(M_S–M_D)$ is minimised

Intrinsic Demand

- Exponential growth

$$M_D[t+1] = M_D[t]e^{k_D[t]}$$

- Demand exponent coefficient updated for each time period



$$k_D[t] = k_{D0} - k_1\left(\frac{M_S[t]-M_D[t]}{M_S[t]}\right)$$

$M_S[t]–M_D[t]$ market driver

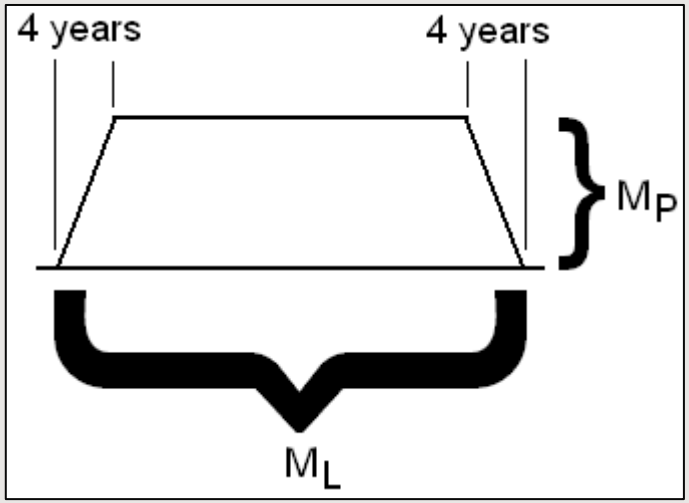
k_{D0} and k_1 constants

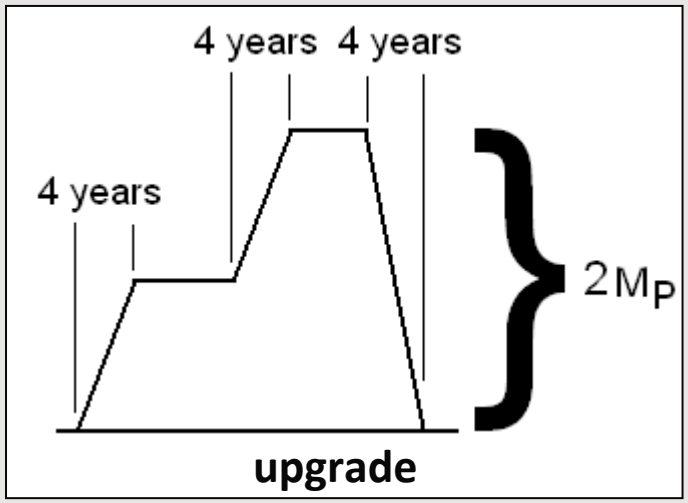
Supply

- Sum of production from each source (mine)

$$M_S[t+1] = \sum_{j=1}^{M\ [t+1]} P^j[t+1]$$

- Source production schedule





Sources automatically brought on-line, off-line, upgraded

Sources Online

$$M[t+1] = \left\lceil M_T - \left(M_T - M[t]\right) e^{-k_S[t]\frac{M_S[t]}{URR}} \right\rceil$$

M_T Total number of sources

$k_S[t]$ Supply exponent coefficient

$$k_S[t] = k_{S0} + k_2 \left(\frac{M_S[t] - M_D[t]}{M_S[t]} \right)$$

$M_S[t]–M_D[t]$ market driver

k_{S0} and k_2 constants

Source Increased Production (Upgrade)

- When (normalised) if the supply-demand gap is greater than a set value then source production is upgraded:

$$M_U[t+1] = \left\lceil k_3 \left(\frac{M_S[t] - M_D[t]}{M_S[t]} - k_U \right) M[t] \right\rceil$$

k_U	normalised limit for upgrade
$M_S[t] - M_D[t]$	market driver
k_3	proportionality constant

In addition to sources being brought online

Demand-Supply Coal for Oceania

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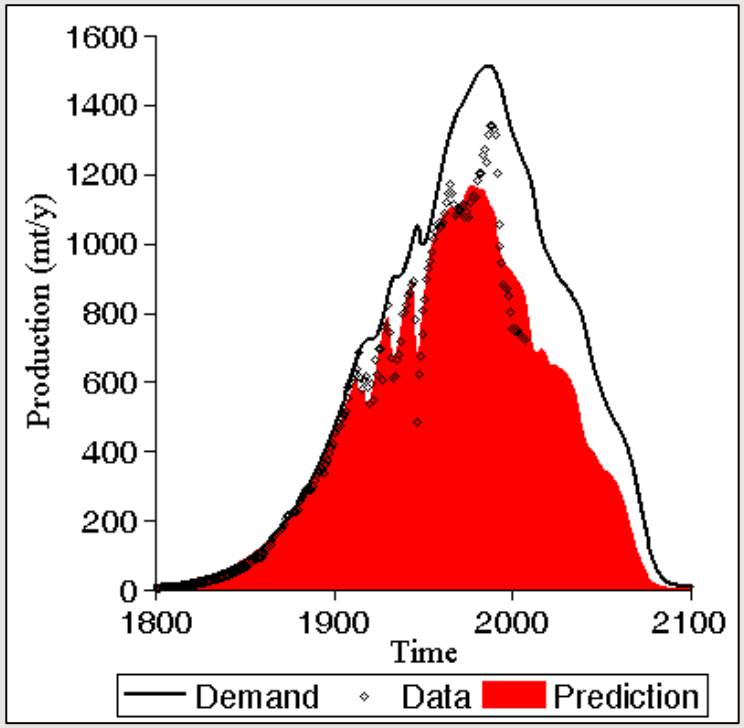
Type	URR (Gt)
Bituminous	51
Sub-bituminous	3
Lignite	40
Other	1
Total	**95**

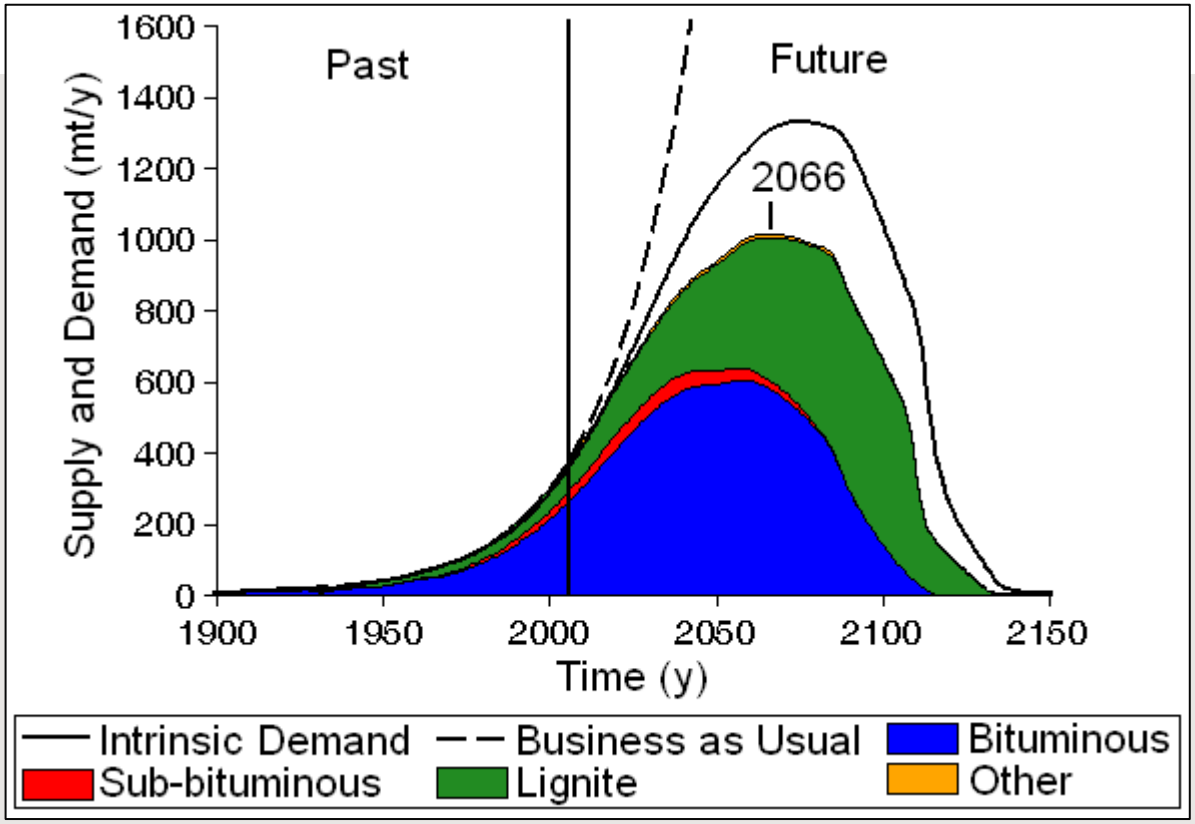
- Average mine production is 0.84 Mt/y
- Total number of mines, M_T, is 1450

Demand-Supply Constants



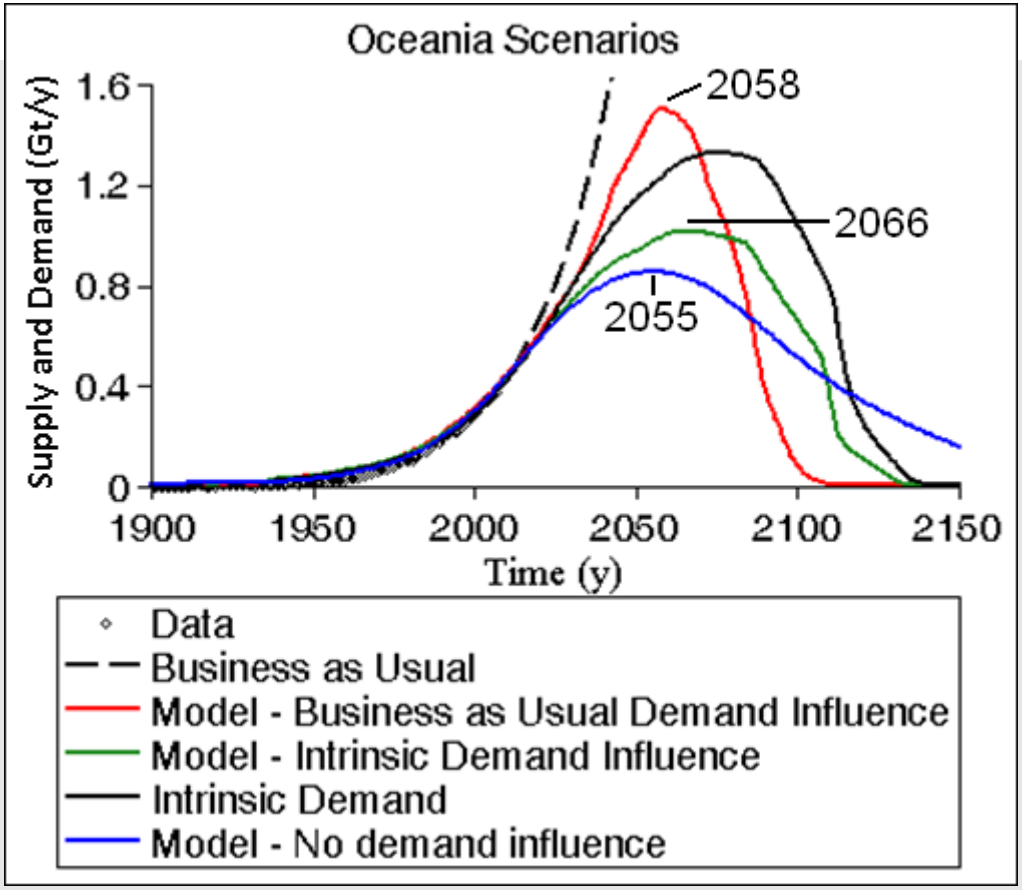
- Based on European coal Market (peaked in1980's)
- Regression to get values for k_1, k_2, k_3, k_U

Demand-Supply: Oceania Coal



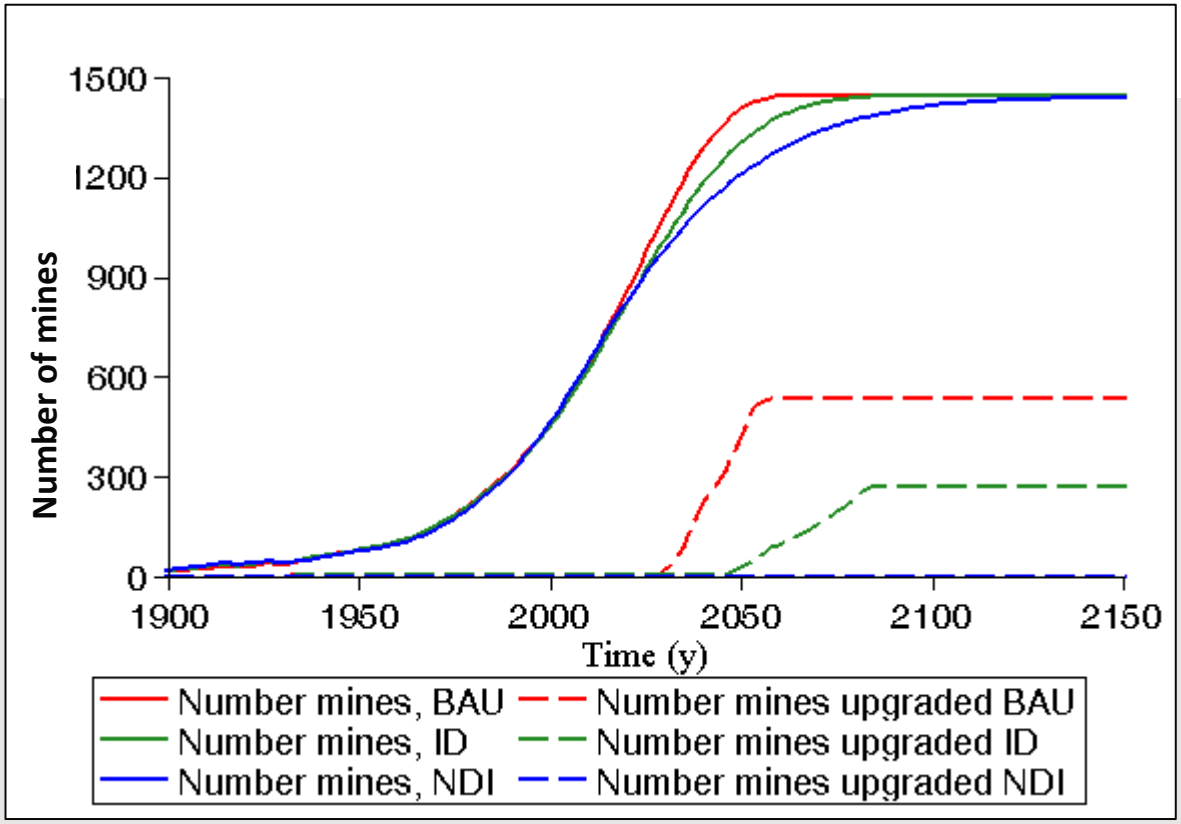
- Peak production takes place in 2066
- Intrinsic demand reduced well below BAU
- Supply curve is not symmetrical bell shape

Effect of Different Demand Drivers



- Peak production BAU (2058), ID (2066), No DI (2055)
- For no demand influence supply curve is bell shaped

Mines online and upgraded



- Number of mines brought online and upgraded increases with increasing demand scenario
- Increased pressure to discover new sources

Conclusions

- Model, based on URR, regulates production from resource sources, to optimise demand-supply for a given market.
- Intrinsic demand can be modified to reflect resource depletion and supply limitations.
- Oceania Coal market peaks between 2055-2066 depending on demand influence.
- Increase rate of bringing mines online must be accompanied by greater exploration activity.

More understanding is needed for demand influence