SCIENCE POLICY RESEARCH UNIT

Emerging Challenges and Unintended Consequences of Innovation: The 'Eroom' Effect and Borlaug's Paradox

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SPRU: Pioneering innovation studies for over 50 years

- Founded in 1966 by Chris Freeman, a pioneer of what is now known as innovation studies
- One of the first interdisciplinary research centres in the field of science & technology policy and management
- Today, SPRU is at the forefront of new ideas, challenge-led research and inspiring teaching

600+ academics have worked at SPRU

~10k publications produced

1,200+ MSc students taught

350+ SPRU PhD theses

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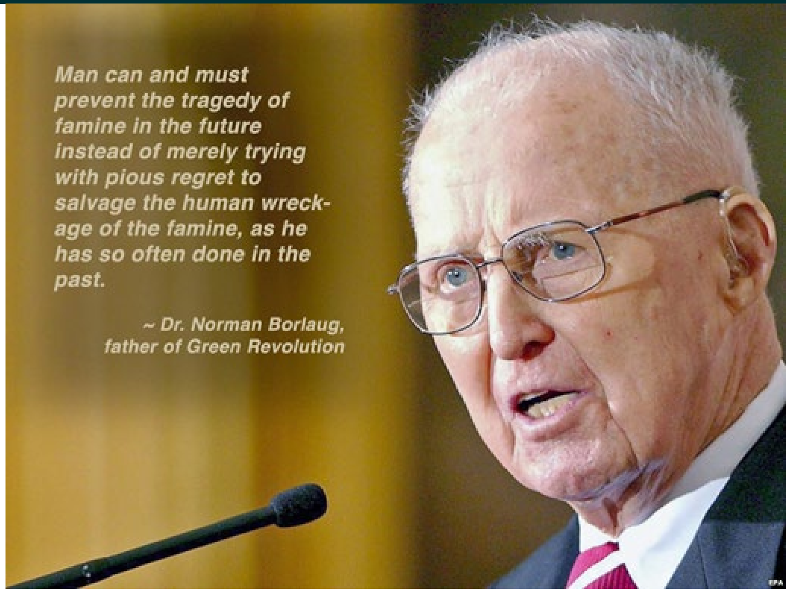
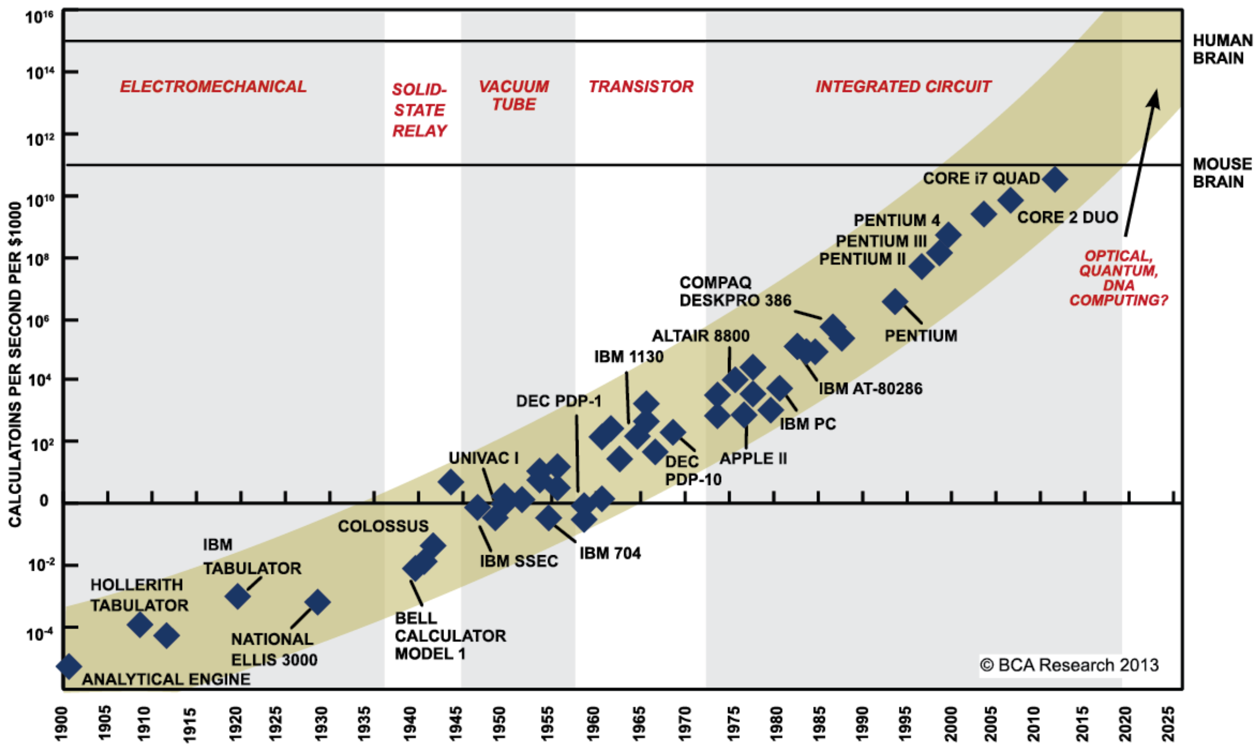
Good Intentions and Unanticipated Problems: Borlaug's Paradox

- Innovation resolves some problems but also creates new ones that must then be addressed (Nelson & Winter, 1982)
- Nobel Laureate Normal Borlaug, 'the man who saved a billion lives from starvation' by pioneering Green Revolution technologies:
  - —R&D & tech transfer initiatives (1930s - 1960s) that increased agricultural production through high-yield crops, use of chemical fertilizers, irrigation, mechanized cultivation, etc.
    - Vastly increased productivity (especially in developing world)
    - But… generated huge environmental impacts
    - Facilitated population growth



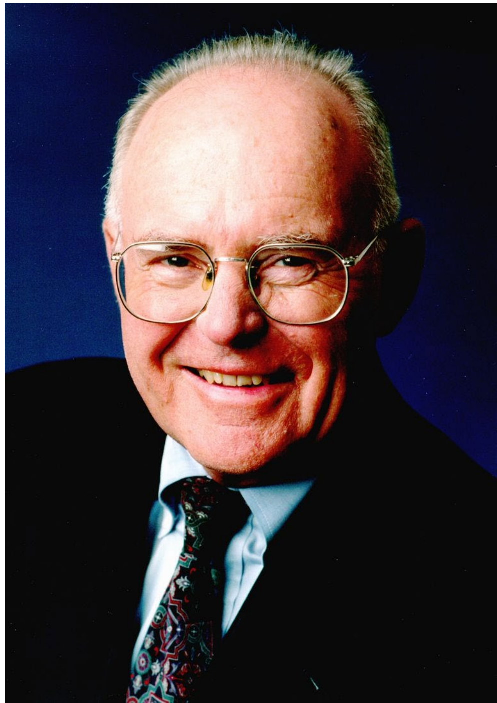
The Power – and Allure – of Innovation: Moore's Law



SOURCE: RAY KURZWEIL, "THE SINGULARITY IS NEAR: WHEN HUMANS TRANSCEND BIOLOGY", P.67, *THE VIKING PRESS*, 2006. DATAPOINTS BETWEEN 2000 AND 2012 REPRESENT BCA ESTIMATES.

With unit cost falling as the number of components per circuit rises, by 1975 economics may dictate squeezing as many as 65,000 components on a single silicon chip.... The advantages of integration will bring about a proliferation of electronics, pushing this science into many new areas.

Gordon Moore (1965)
Founder, Intel &
Fairchild Semiconductor



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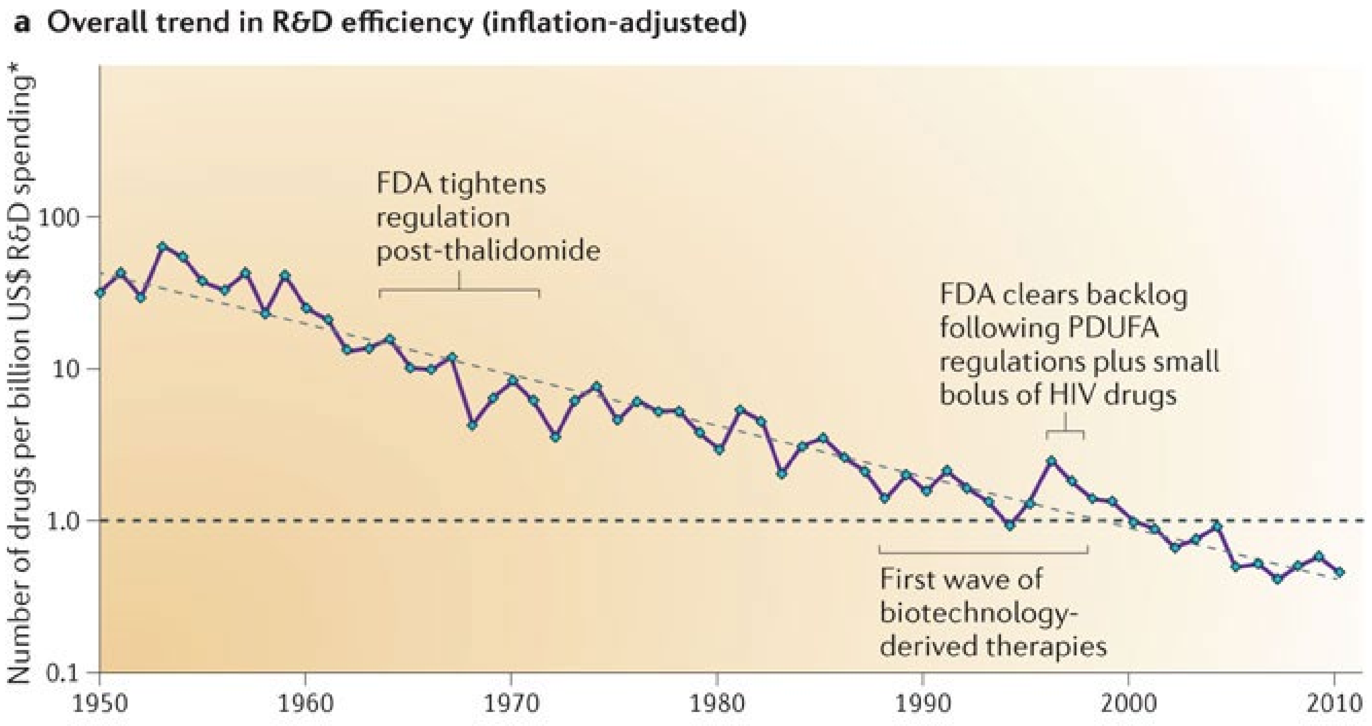
But is Moore's Law Universal? 'Eroom' Effect (Scannell et al. 2012: 191)



R&D efficiency, measured simply in terms of the number of new drugs brought to market by the global biotechnology and pharmaceutical industries per billion US dollars of R&D spending, has declined fairly steadily.

- Regulators increasingly cautious (e.g. Thalidomide, nuclear power)
- High R&D offer first mover advantage, high barriers to entry
- New products have to be substantially better to warrant investment, "*better than the Beatles*" phenomena, resulting in monopolistic tendencies

Theories of Regulations

- Regulations a response to public demand over inefficient, inequitable market practices, benefitting society as a whole rather than any particular vested interest (Pigou, 1932; Stigler, 1975)
- Capture theory of regulation: If/ why gov’t regulation favors larger, older producers over new entrants (Carpenter, 2004):
  - Can absorb delay costs, enter market niches prioritized by policy under pressure from organized consumers earlier (AIDS sufferers)
  - Firms known by regulator typically seen as less uncertain: … *familiarity holds even in cases where the familiar firm has a bad reputation for product safety*

Genome Canada Large-Scale Applied Research Projects

- Not-for-profit funding agency mandated to "*develop and implement a national strategy for supporting large-scale genomics and proteomics research in Canada*"
- "GE3LS" (Genomics-related Ethical, Environmental, Economic, Legal and Social) component:
  - Proactive approach to address public concerns over genomics
  - Recognition that linear "technology push" model left promising technology sitting on the shelf
  - All grants need to emphasize "benefits to Canada"

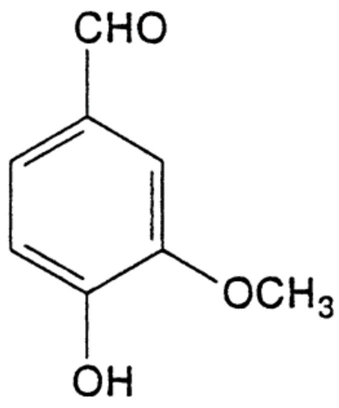
See Hall et. al., 2014
Hall et al, (2013); Genome Canada GPS Policy Brief No. 7
www.genomecanada.ca/medias/pdf/en/InnovationContinuum_Policy-Directions-Brief.pdf

Lignin transformation technologies for sustainable biomass products

University of British Columbia (science) and Simon Fraser University (social science) based project exploring how genomic approaches can transform lignin to replace petroleum in food additives, resins, carbon fibres, biofuels, etc.

Lignin-based vanillin

- World's most widely used flavouring, aroma agent
- Proposed fermentation process uses soil bacteria strains to convert lignin into vanillin



Vanillin

TCOS Methodology

Consultation with Scientific Teams developing AI to identify potential applications, key issues, stakeholders

Identify/ interview key stakeholders for potential applications

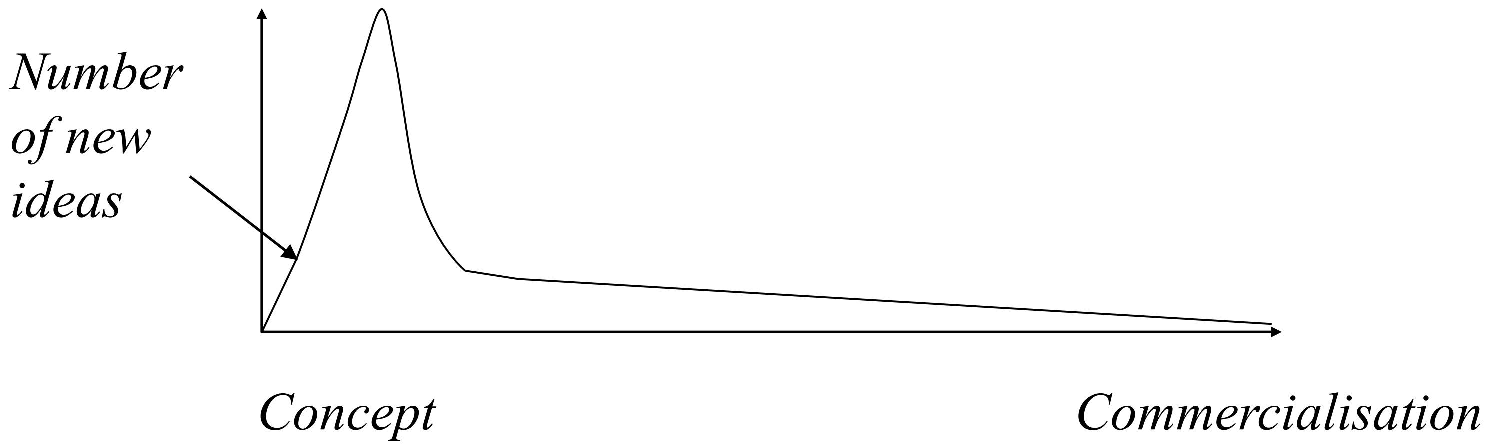
TCOS Levers & Hurdles Analysis

- ***Tech.*** e.g. production scalability, product consistency, durability, etc.
- ***Commercial*** e.g. Industry structure, competitive dynamics; consumer needs; willingness to pay, etc.
- ***Org.*** e.g. IP protection, requisite complementary assets & competencies
- ***Societal*** e.g. reg. hurdles, public perception, env. impacts; social/env. benefits over incumbent technologies, etc.

Feedback to science teams, publications

The Challenges of New Product Development

Clark and Wheelwright, 1993



The Challenges of New Product Development

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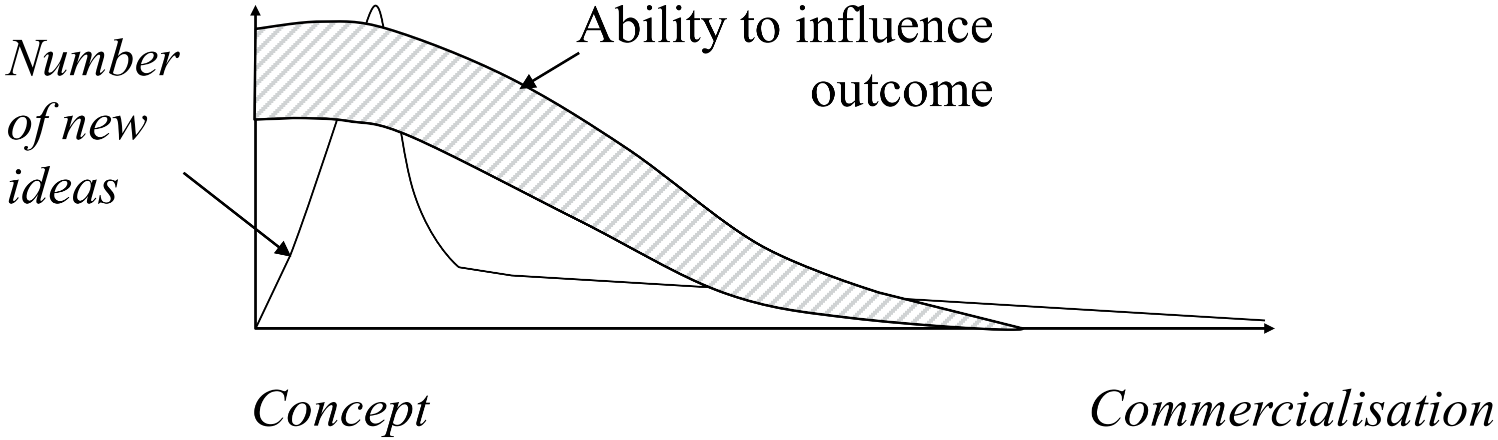
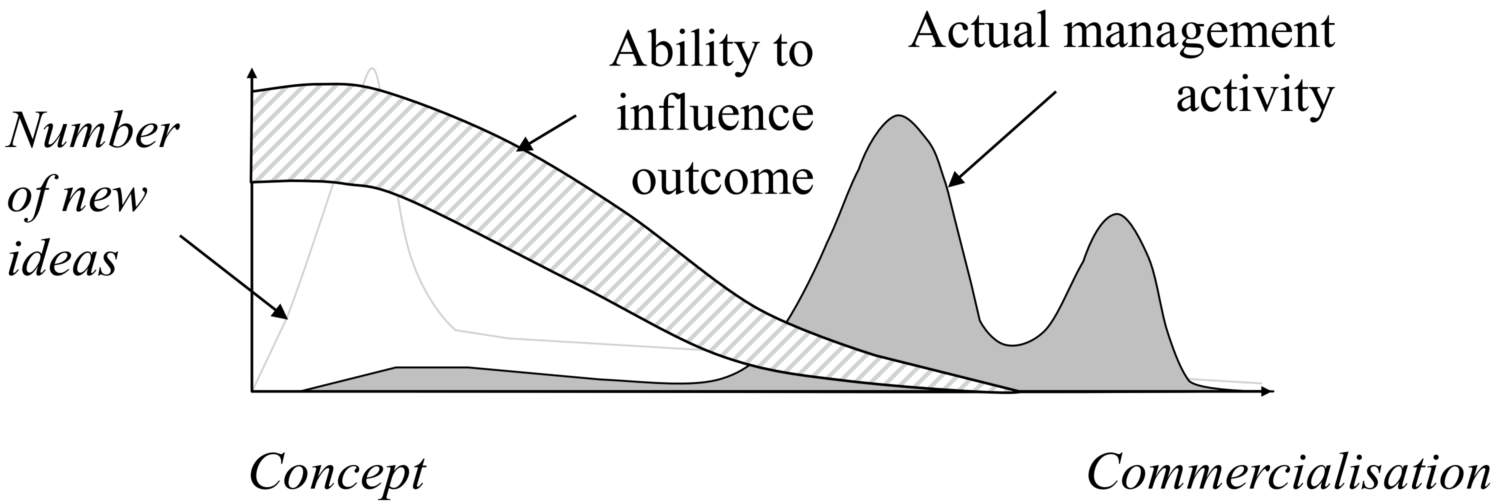
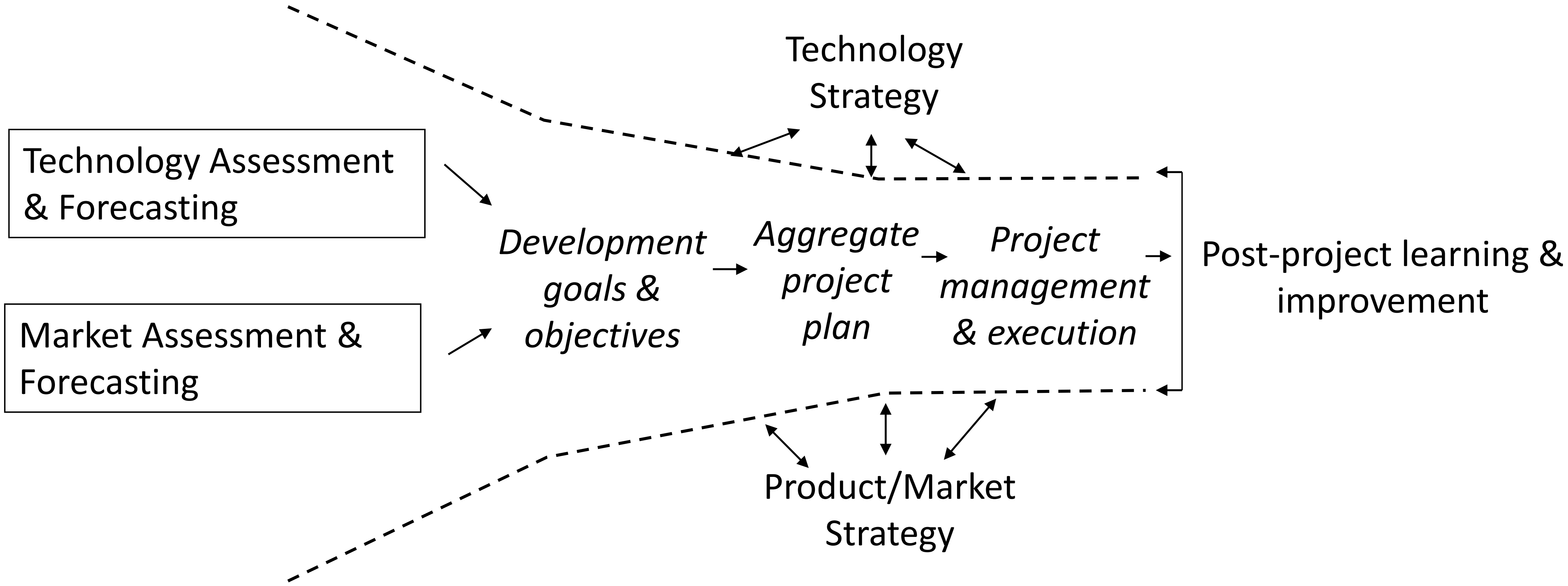


The Problem of New Product Development

Clark and Wheelwright, 1993



‘Contemporary’ Development Funnel
Clark and Wheelwright, 1993

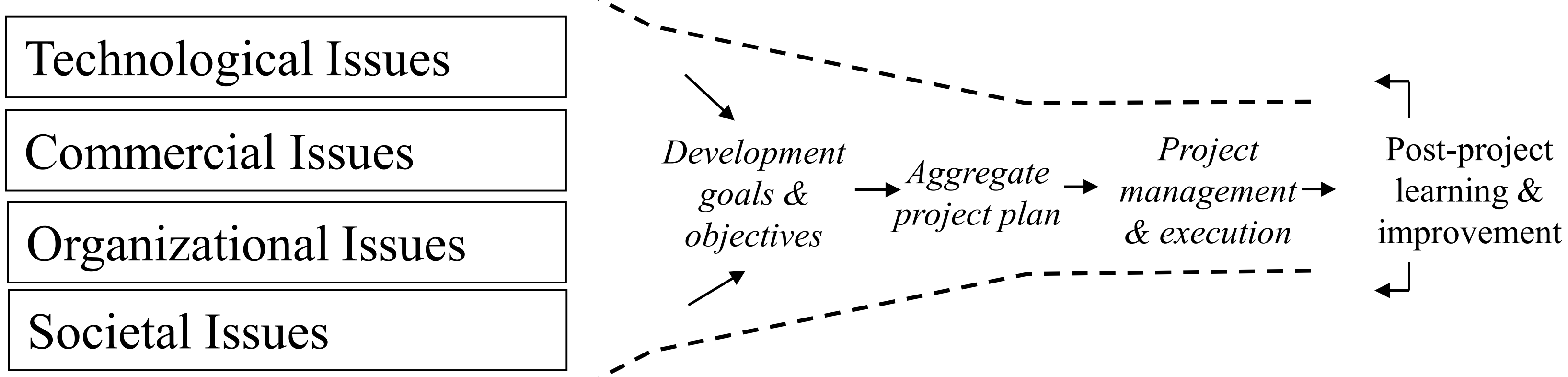


TCOS Framework

Martin, 1994; Hall & Martin, *R&D Mgt,* 2005, Matos & Hall, *J of Op Mgt*, 2007; Hall et. al., *TFSC*, 2011, Hall et. al.; *Technovation*, 2014; Hall et. al., *CMR,* 2014; Hall et al., *Small Bus Ec,* 2019, etc.

Development Funnel plus:

Organizational Issues, e.g. firm specific capabilities, intellectual property protection, complementary assets (Teece, ‘86; Martin, ‘84), e.g. just because a technology works and it’s commercially viable, doesn’t mean that your organization can profit from it



Societal Issues, e.g. how diverse secondary stakeholders may affect, or be affected by technology. Differs from TCO uncertainties:

- More interacting variables (more stakeholders, some which may be difficult to identify - complexity and ambiguity)
- ***<u>Requires different heuristics</u>***

Summary of TCOS Levers (L) and Hurdles (H) Analysis for Lignin-based Vanillin

Technological

L	• Demonstrated proof of principle • Advantages of producing at lower temperatures/ pressures
H	• Lab yield still low - "***The key issue is really the productivity***" • Process needs to be changed to meet lucrative ***"natural"*** market

Organizational

L	• Patentable, can be out-licensed • Potential 'low hanging fruit' to establish legitimacy of lignin
H	• ***Small market may not meet Tech. Transfer Office thresholds*** • Lack skills for managing regulations (e.g. '***natural***' certification)

Commercial

L	• Petroleum free • Abundant, renewable, stable supply • ***Varying vanillin prices - potential eco–product sold at a premium***
H	• Skepticism re: lignin-based products • Requires major investment from a pulp mill for small global market • ***Varying vanillin prices – low margin if not approved as 'natural'***

Societal

L	• Increasing concerns over petroleum-based ingredients • Lower CO_2 emissions
H	• **Regulatory ambiguity re: 'natural'** • NGO protests against synthetic vanillin: "*extreme genetic engineering in our food*" , "*very un-natural new ingredient", "what it means for [poor] vanilla farmers."*

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Varying Vanillin Prices – Hurdle or Lever?

RHOVANIL®
NATURAL

Source of vanillin	**Market price**
Guaiacol vanillin (synthetic)	\$12-15/Kg
Borregaard lignin vanillin (synthetic)	\$13-16/Kg
Solvay-Rhodia catechol vanillin (‘*natural like’ (!?) US only*)	\$70/Kg
Solvey-Rhodia ferulic acid vanillin (natural)	\$700/Kg
UBC’s wheat straw fermentation (preliminary est.)	\$912/Kg
Vanilla bean (natural)	\$1200-4000/Kg

Regulatory Nuances

According to a Canadian Food Inspection Agency chemistry specialist (2014):

> *The production of vanillin from wheat straw using bacteria fermentation would <u>not</u> be considered natural as it utilizes chemicals in the [separation] process...*

- If the separation process can be changed to use only natural substances (e.g. vegetable oil), then it may quality as natural flavoring
  - Change the process or induce regulatory reform?
  - Exploit the technology elsewhere, e.g. US, China, where the process may meet 'natural' regulatory criteria?

Calls for an Eco-value proposition

If only T, C or O are explored, then technology would likely stall:

- Small market but relatively high investment requirements may not meet University Tech Transfer Office (TTO) threshold criteria
- TTOs have limited resources, difficulties handling non-patent IP, inventions for small markets, ‘passive’ industries

S seems to be the key value proposition:

- Demand for lucrative but ambiguous ‘natural’ market is key - UBC’s current $912 costs will likely drop but not to the level of synthetic
- But… understanding nuances of regulatory regimes (e.g. Canada, US, EU) may be too formidable for scientists and TTO

EROOM in Agriculture

- Public, NGO concerns over transgenics resulted in major regulatory hurdles, often more than lab costs:
  - Only a few large multinationals (e.g. Monsanto) have adequate resources to bring new transgenics to market
  - Unlikely to be viable unless only one competing seed per segment (monopolistic tendencies)
- High regulatory barriers may hinder public sector institutes with mandates for societally beneficial technologies

Brazilian Agricultural Research Corp (EMBRAPA)'s Transgenic Cotton

- Gov't research institute mandated to *develop research, development and innovation solutions for the sustainability of agriculture, for the benefit of Brazilian society*
- Developing transgenic cotton to reduce env. impacts in large scale farming, and later small farmers
- **Brazilian Cotton**: After years of major growth, cotton was devastated in the 1980s by boll weevil (*Anthonomus grandis*)
  - Production abandoned, collapsing the economies of many communities
  - Originally 5th world cotton producer and major exporter, Brazil suddenly became one of the largest importers

EMBRAPA's Future Transgenic Cotton

- Naturally colored varieties that produce edible oil and suitable in arid areas
- Although tech. feasible, regulatory approval may be beyond their resources, or take too long: ~6 years for upstream research, 10 for downstream phases
  - Downstream costs increasing due NGO opposition because it concentrates farming, resulted in major env. Impacts, forced small-scale farmers off the land (Hall et al., JBE, 2008; CMR, 2014)

    "***It's depressing knowing that I may be dead before this product is approved***" (EMBRAPA scientist, 2015)

- EMBRAPA may have to partner/sell to Monsanto…

Did Greenpeace give Bayer/ Monsanto a monopoly?

Have they created a ‘Borlaug's Paradox’?

Implications and Conclusions

- TCOS analysis can identify challenges (hurdles) and opportunities (levers) for improved technology development & commercialization
  - Multidisciplinary approach, using different heuristics
  - Actively ***searches*** for hurdles & levers at an early stage of technology development
- Are downstream 'EROOM' costs becoming greater than science/engineering hurdles?
  - Can advocacy groups, which have played an important role in increasing regulatory standards, differentiate their opposition to new technologies?
  - Implications for next generation technologies?
  - Role of social scientists?
  - Over-bureaucratization, accountability, etc. – have the proxies become the goals (Langford et al. 2008)…?

Many Thanks!

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