# How does innovation take place in the mining industry? Understanding the logic behind innovation in a changing world

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# Motivations

**1.Mineral resources contribute to export but limited in generating innovation that leads to development**

**2.Innovation contributes to development in following ways:**

1) **Productivity upgrading: getting more for the same amount of investment**
    1) Adding value to the final product
2) **Spillover effect: generating growth in seemingly unrelated activities to scale up its impact**
    1) Creation of supplier network: backward linkages
    2) Creation of industry with which the knowledge is shared: side linkages
3) **Meeting Social and environmental agendas (SDGs)**
    1) Income inequality, employment, inequality to access to basic services(water, energy)
    2) Environmental sustainability(E.g. Climate change), Local ecological degradation(contamination)

**3. Understanding how innovation take place in mining paying attention to: current changes**

Emergence of digital technology, social and environmental concern

# Purpose

- Understand Innovation Pattern in mining sector
- **H**ow (Innovation take place in mining)?
  - **W**hat (kind of innovation are being introduced?),
  - **W**ho (in the value chain innovate?)
  - **W**hich (segment of value chain innovation are likely to be introduced?)
  - **W**hen (innovation takes place?),

  From Using existing literature, model, analysis and data

What sort Policy and enabling environment is necessary?

# Characteristics of innovations in mining from literature

- Restricted by the type of infrastructure installed in the mine (e.g 20-year cycle)
- Requires upfront large investment to introduce radical changes

Upgrading of productivity via scale economies

- Achieved by introducing machines  (embodied technology)
- Focusing on process efficiency aiming to reduce cost
- Often involves coordination with suppliers (e.g. logistics)
- Aiming to maximize mineral extraction
- Knowledge comes from diverse sectors (characteristics of NR based activities)
- Appropriation of production knowledge is not so important for the miners
  - Locally specific, exposed sites
  - Limited applicability, limited actors, consortium
- Knowledge/information on exploration is critical for the miners

# Simple production functions of mining 1

- Profit( P) is Revenue (R) minus Cost ( C)
  - P=R-C
- Cost consist of Variable Cost (VC)and Fixed Cost (FC)
- Fixed cost is the cost that is required regardless of how much one produces (cost of operation, infrastructure, machineries, etc.)
- Variable cost increases according to the volume of production (additional inputs, labour, production costs)
  - C=VC+FC
- Revenue depends on Price per unit of mineral (PR)*Volume of minerals extracted(V)
  - R= PR * V

**Restriction**

**Price is exogenous because it is Commodity.**

# Simple Production function of mining 2

**Profit=Revenue-Cost  MAX (P)=MAX(PR*V)-MIN(VC+FC)**

**Maximize Revenue (PR* V)** or **Minimize Cost (VC+FC)** or do both

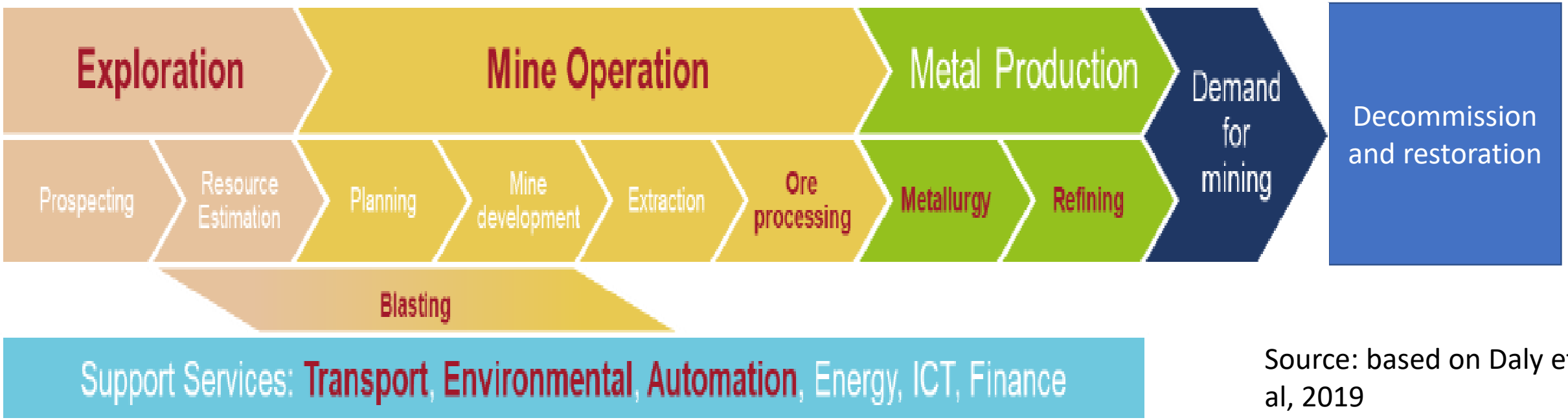
**1.Maximize Revenue: firm can actively influence V (volume)**
**Improve the mineral extraction efficiency:**
Explorations (better deposit) or Beneficiation (mineral extraction extractive metallurgy e.g SX-EW, bioleaching etc.)

**2. Minimize Cost: important to reduce Fixed Cost**
Introduction of machines to optimize process with digital technologies (e.g. autonomous logistics—from scale up in size)
Organizational arrangement (optimal service maintenance)

**Which segment of value chain in mining innovation likely to take place?**

Explorations phase, beneficiation (process)and Fix cost reduction (of various kinds of activities) concerns suppliers

# What are the activities in mining ?



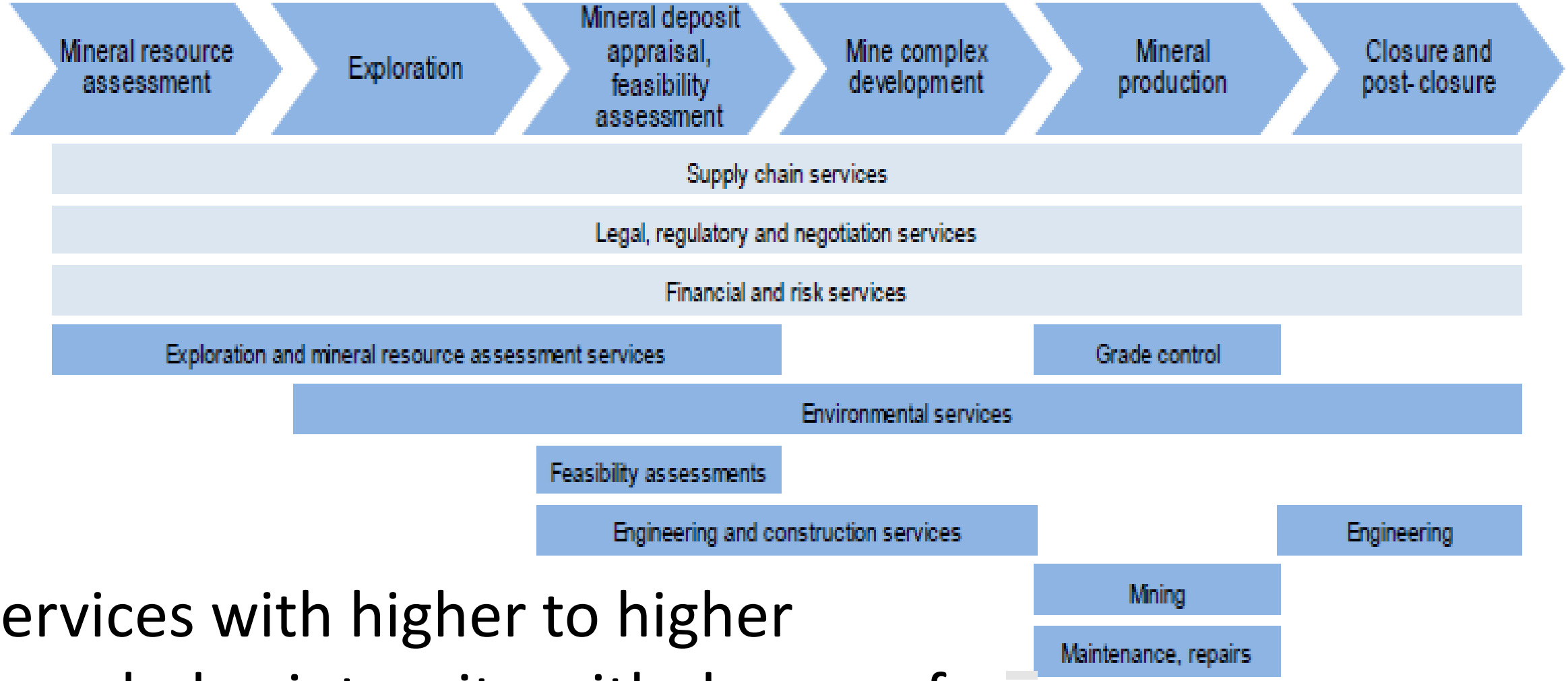

Source: based on Daly et al, 2019

**Main line of business activities:** Exploration (Blasting), Mining operation (Ore processing), Metal production (Metallurgy, Refining) and Decommission

**Supporting services(specific to mining)**: Transport, Environmental and Automation

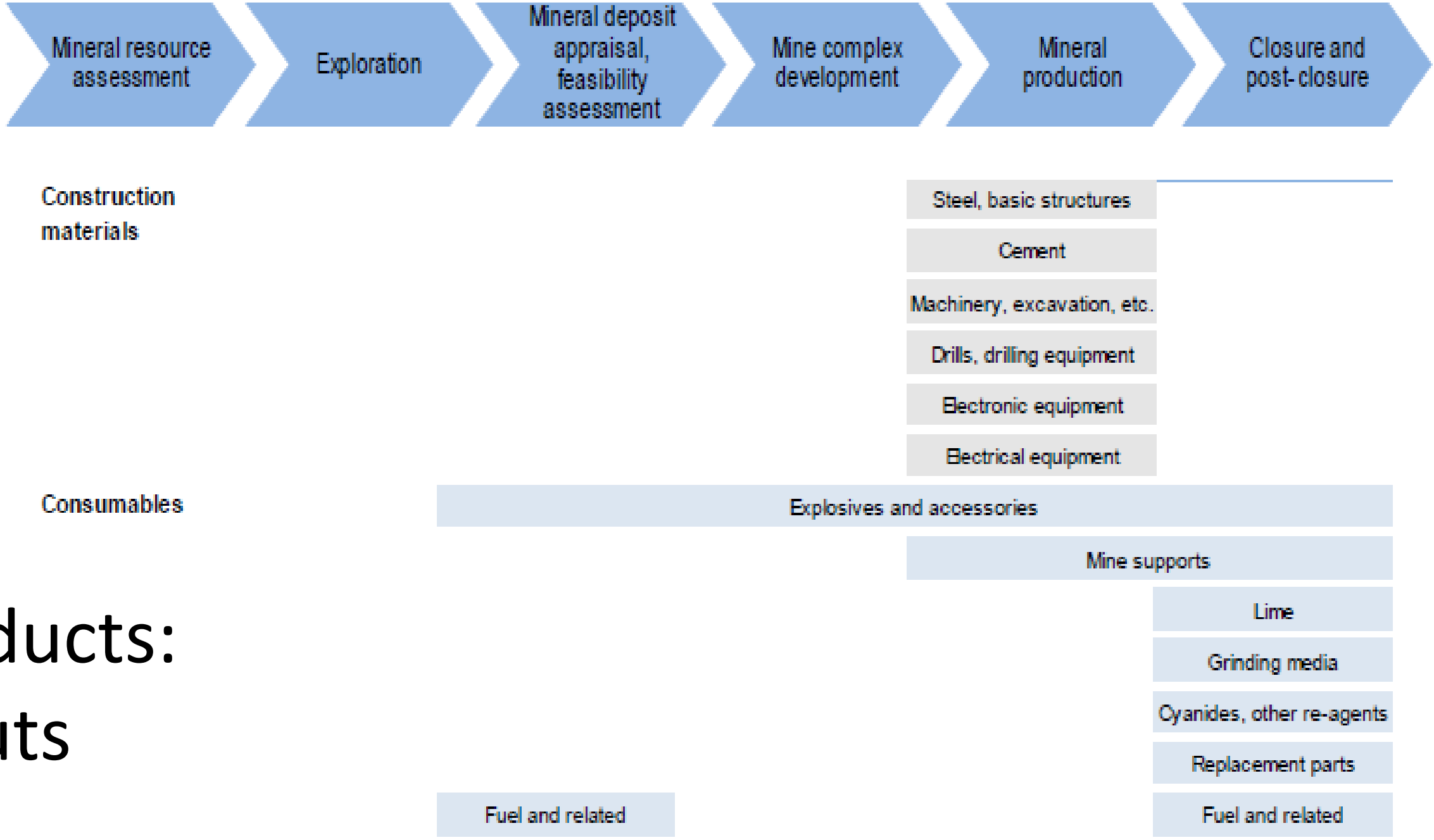
**Generic services:** finance, energy, ICT, water, education, health etc.

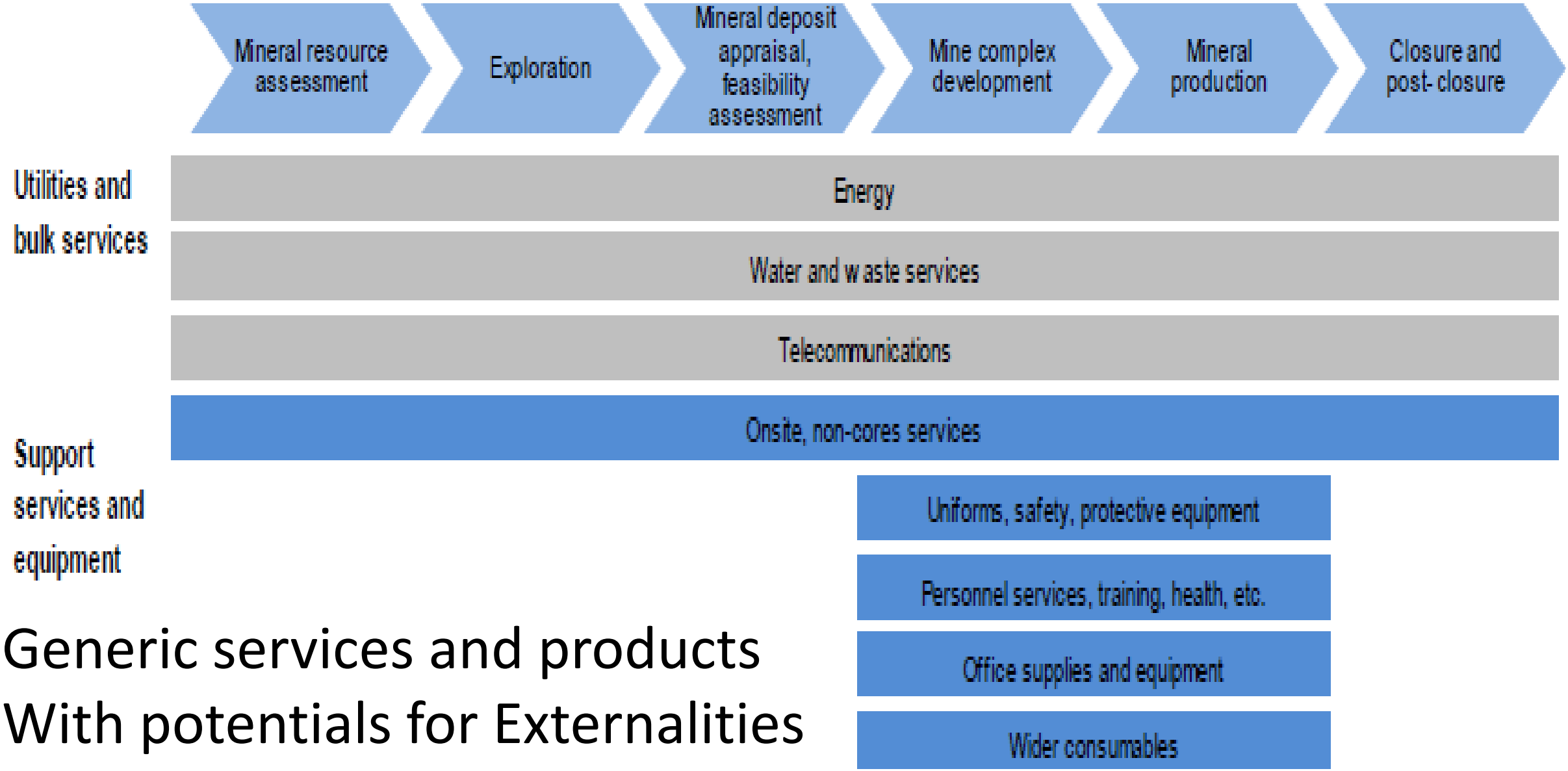
# What sort of innovative activities exist in mining ? Suppliers




Services with higher to higher knowledge intensity with degree of association to mining

# Products: inputs






# Generic services and products With potentials for Externalities to regions

# Changes that are taking place in mining sector

- Increasing role of suppliers, especially Mining Engineering Technology Services (METS) (local and global)
- Decentralization, longer extension of global value chains of suppliers

Global Value chains

- Increasing use of knowledge intensive services and suppliers
- Emergence of digital technologies for optimization

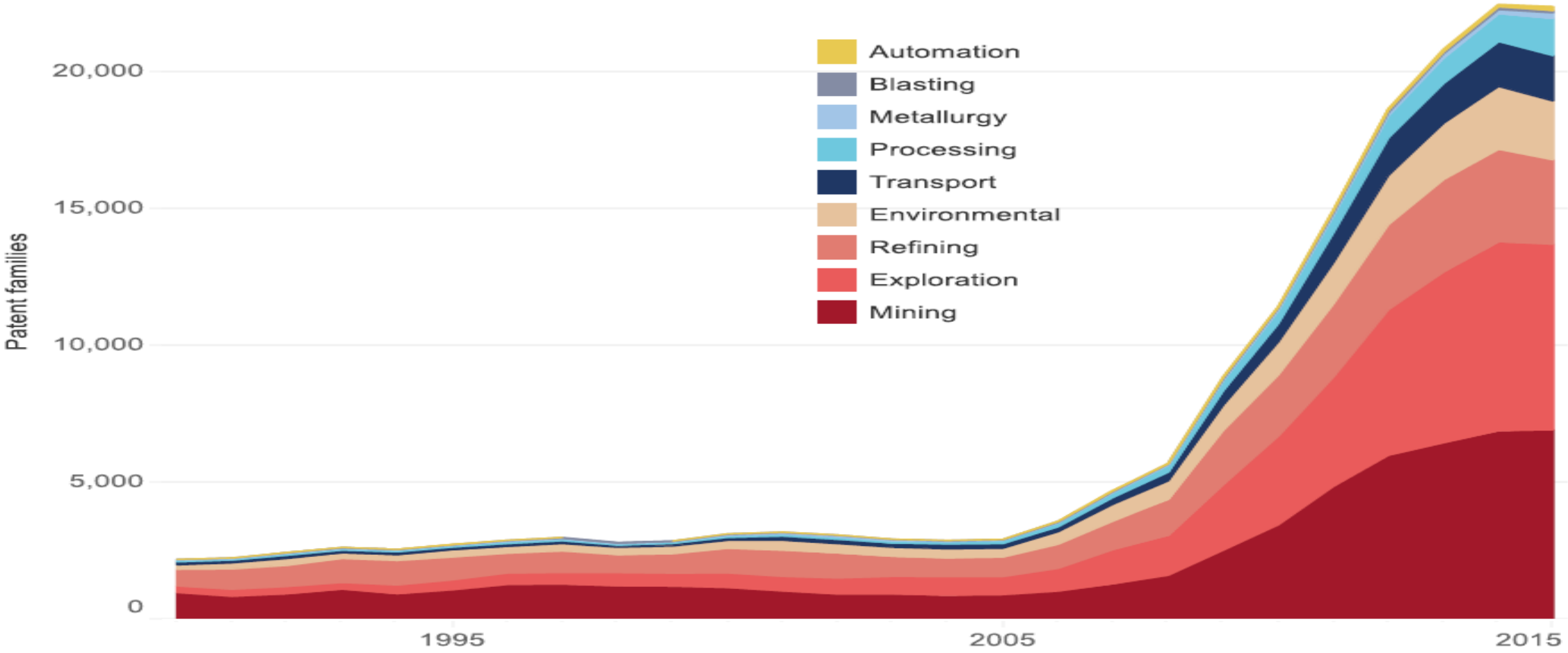
Technology & innovations

- Fluctuation of prices(copper): some recovery after the decline
- Decreasing ore grades
- Increasing social conflicts (safety, rights of local community) and environmental concerns (global, i.e. CO2 emissions, and local ecology)
- Increasing resource nationalism (local contents requirement)
- Lack of human resources to deal with digitalization
- Lack of suppliers capable to respond needs of mining firms (start-ups, open innovation?)

Challenges

# Increase in patent applications for mining sector

Figure 19: Mining and METS firms by technology, by earliest priority year

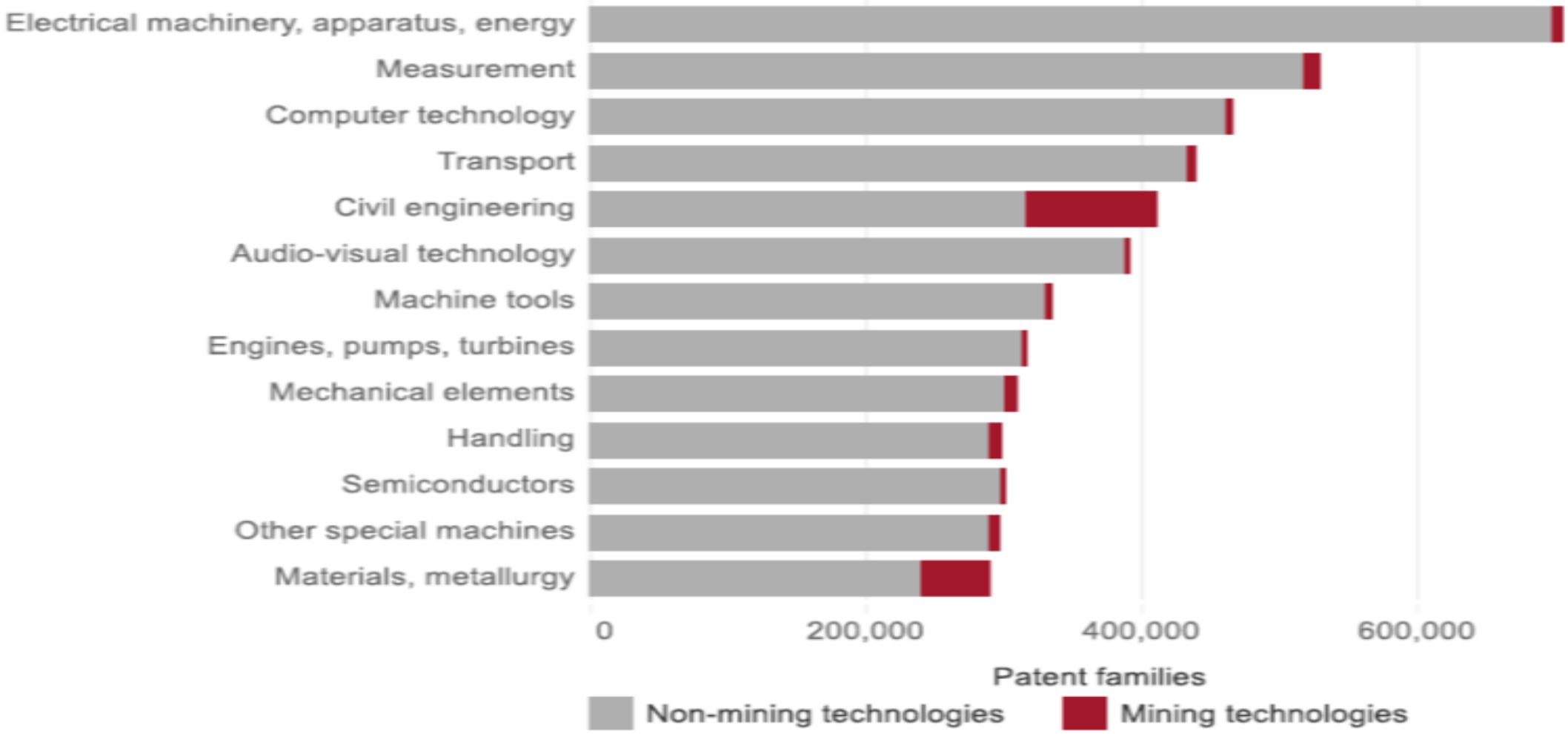



*Source: WIPO Mining Database (firm subset)*

Daly et al, 2019

# These patents are not from mining technologies

Figure 20: Patent families of mining firms by WIPO technology field

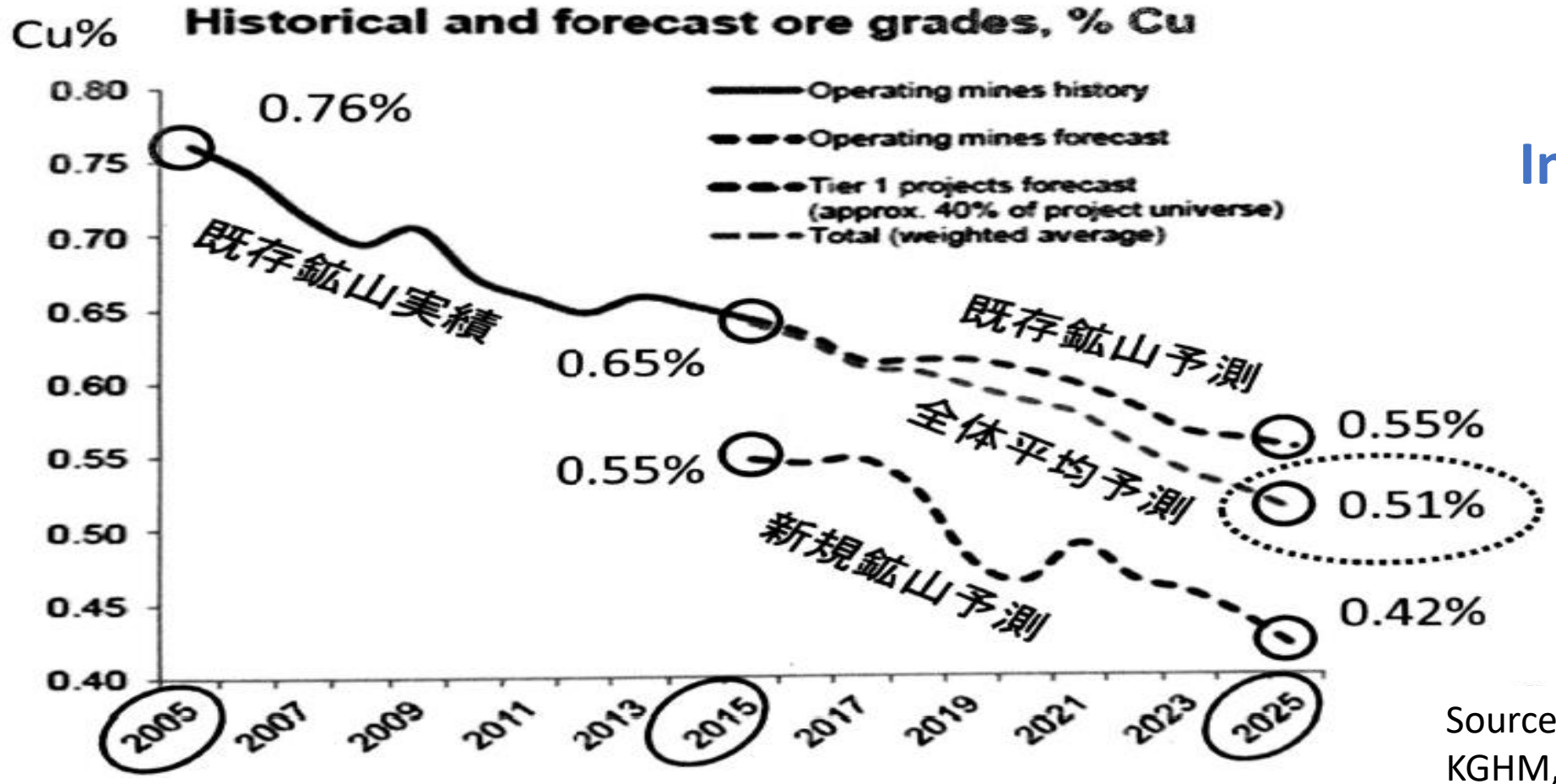



*Source: WIPO Mining Database (firm subset)*

# Degradation of ore quality

**Ore require more cost in**
-Exploration in difficult places
-Beneficiation
-Processing and refining

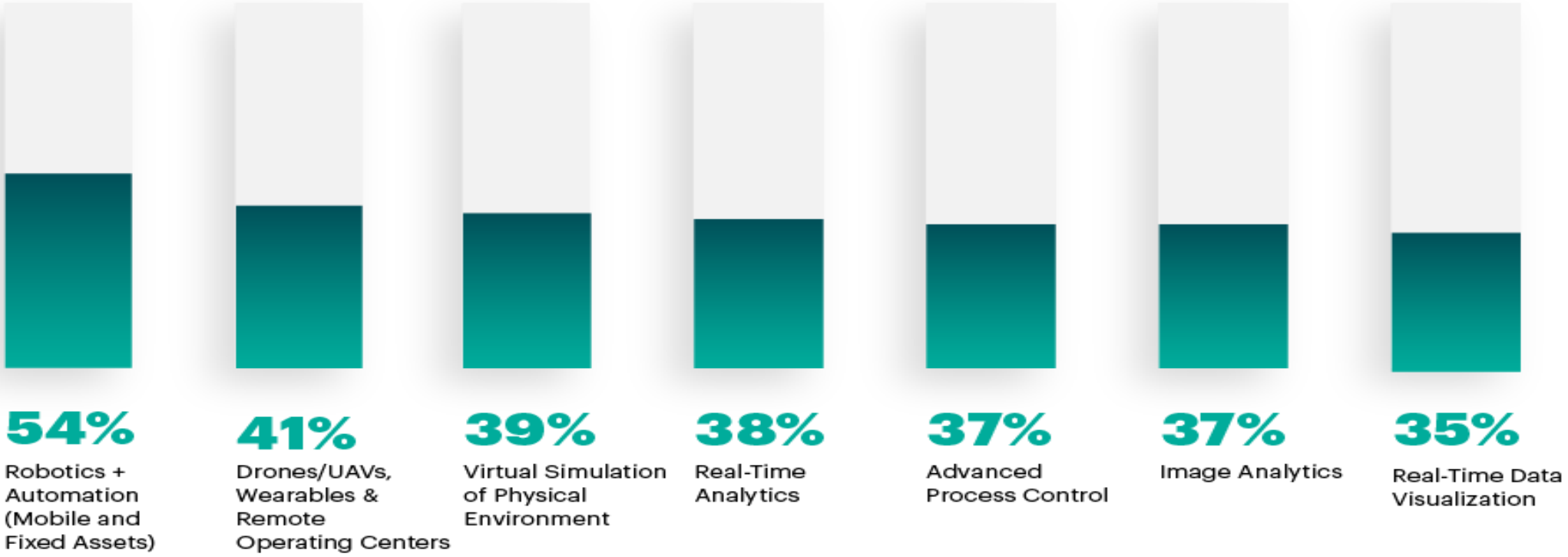
**Increase in cost**




Source Kamil Jakowski, KGHM, 2015

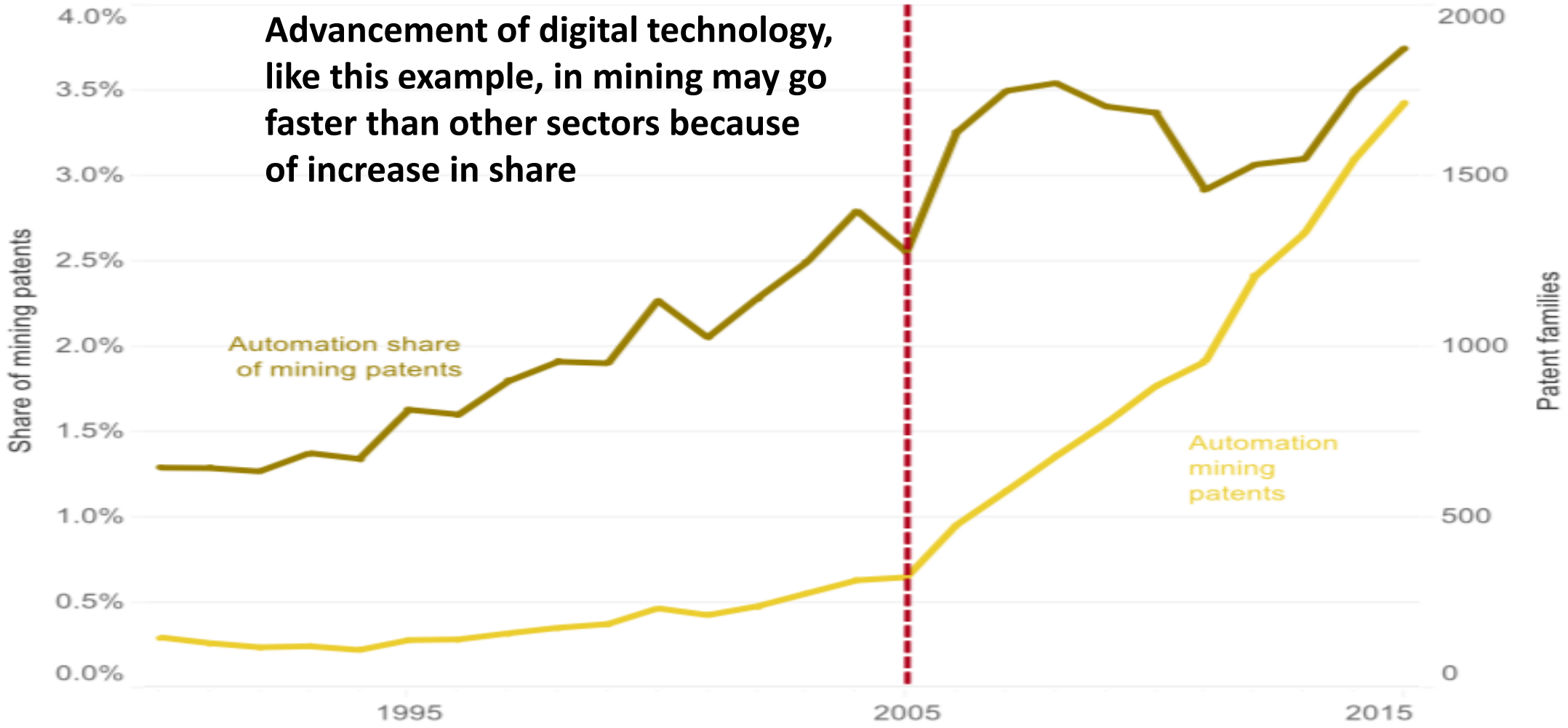
# Digital technology penetration

DIGITAL TECHNOLOGIES ALREADY EMPLOYED OR WILL BE EMPLOYED IN THE NEXT 3-5 YEARS IN MINING OPERATIONS




source: Accenture, 2017 https://www.accenture.com/us-en/insight-digital-technology-mining

Figure 12: Patents families in automation class over time




*Source: WIPO Mining Database (technology subset)*

# How Innovation takes place in mining?

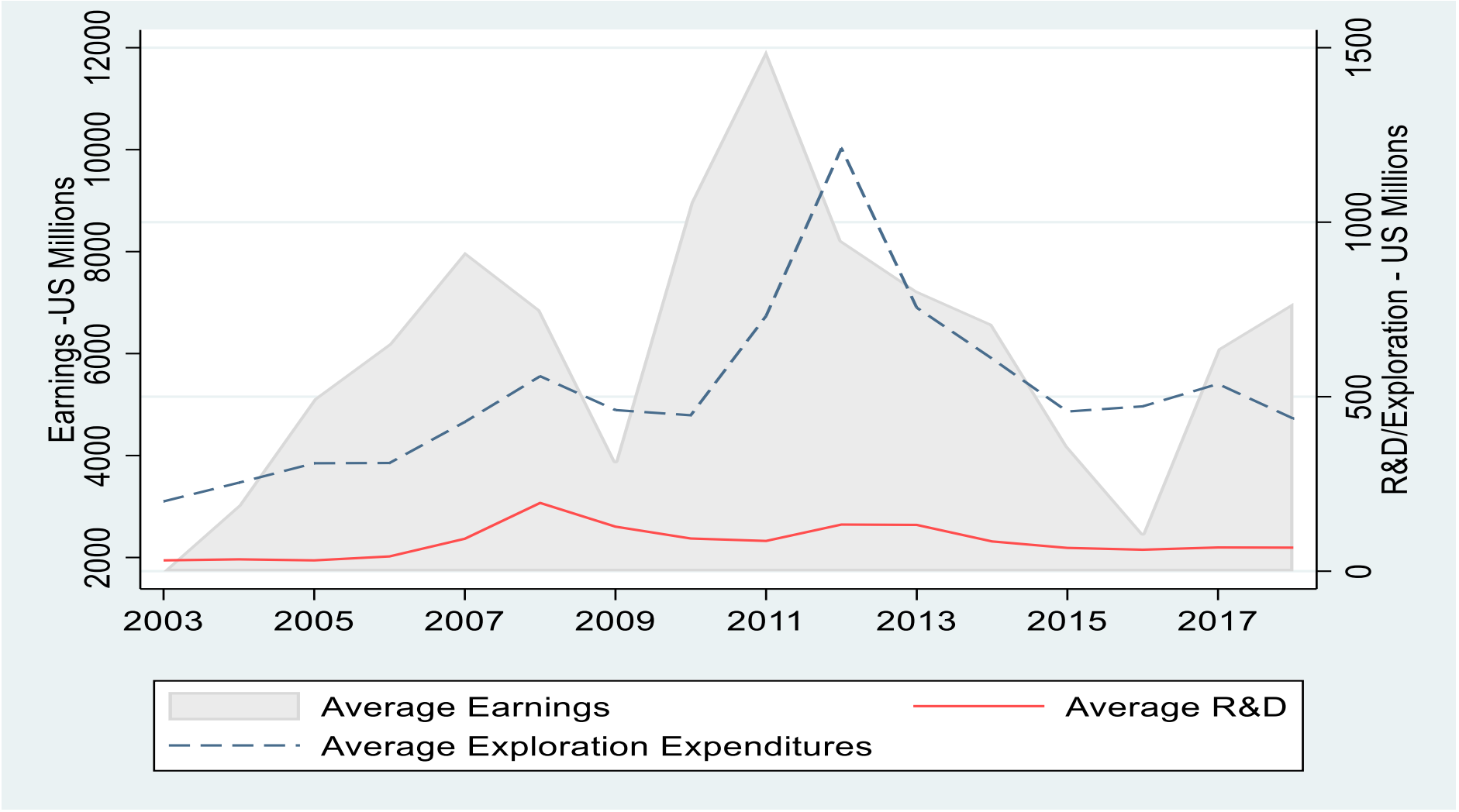
- When (at what moment) innovations are made?
- Who innovate and what?
- Where (which segment of GVC) is innovation likely to happen?
- What sort of innovation are they?

Based on existing evidence as follows:

- R&D expenditure
- Investment in exploration (proxy to R&D in mining)
- Patent
- Input-output
- Roadmaps (annex)

# When does it take place? From the investment data

Average R&D and exploration investments for the largest mining firms: BHP Billiton, Rio Tinto, Anglo American and Glencore from 2003-2018 (US millions)




Investment in Exploration is substantially higher than R&D. It follows average profit. The distribution is higher in Canada Australia the US, and China

Investment on knowledge R&D It also follows average profit.

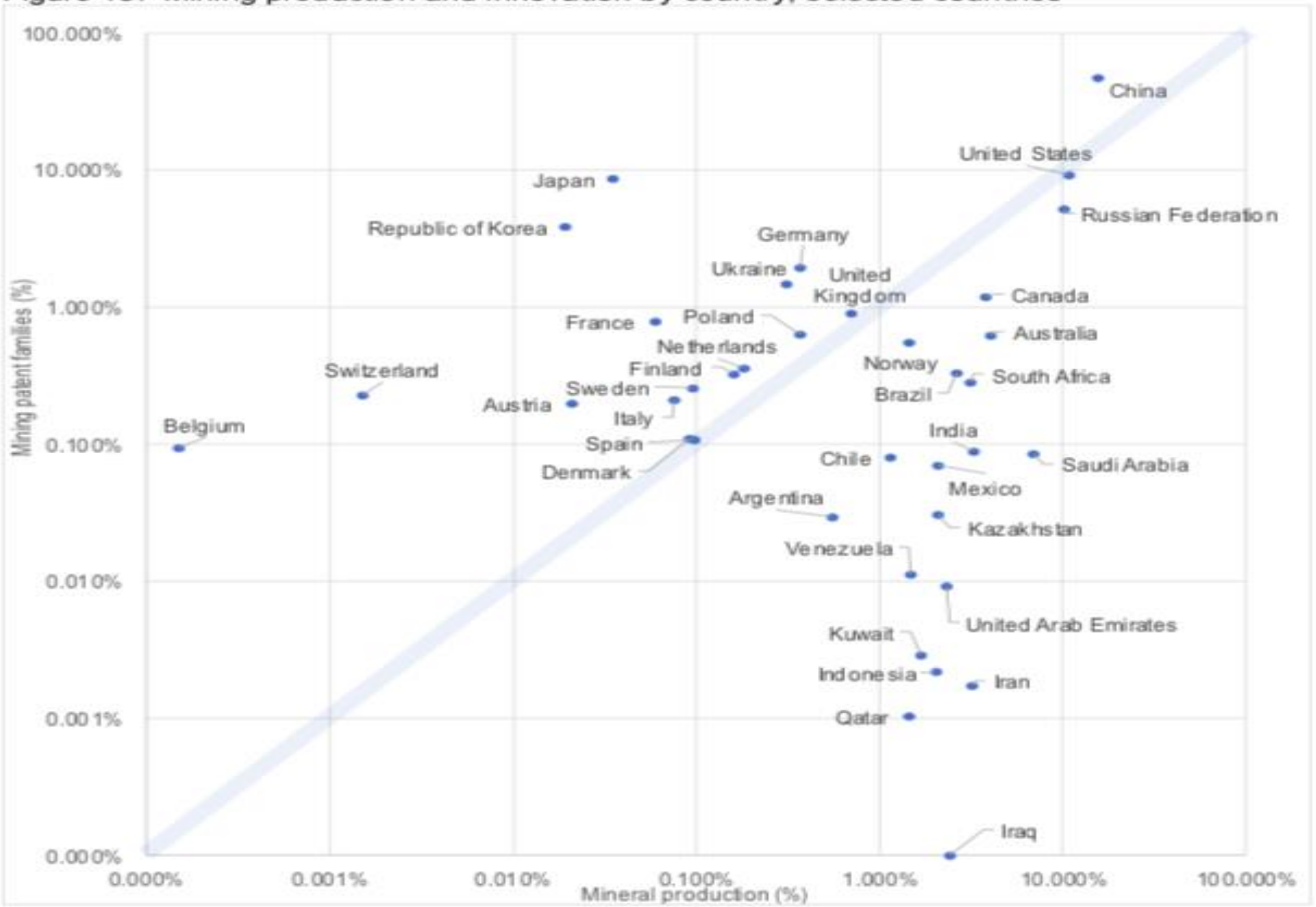
# Where does the knowledge investment made? Proxy by patent

| | Automation | Blasting | Environmen | Exploration | Metallurgy | Mining | Processing | Refining | Transport | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 1970-1995 | | | | | | | | | | |
| Suppliers | 19 | 55 | 1,966 | 3,406 | 329 | 6,125 | 433 | 5,803 | 1,526 | **19,662** |
| | 0.1% | 0.3% | 10.0% | 17.3% | 1.7% | 31.2% | 2.2% | 29.5% | 7.8% | 100.0% |
| Mining | 3 | 73 | 1,368 | 3,729 | 116 | 1,126 | 559 | 3,720 | 159 | **10,853** |
| | 0.0% | 0.7% | 12.6% | 34.4% | 1.1% | 10.4% | 5.2% | 34.3% | 1.5% | 100.0% |
| 1996-2015 | | | | | | | | | | |
| Suppliers | 62 | 452 | 5,616 | 13,316 | 334 | 14,845 | 1,910 | 10,075 | 6,124 | **52,734** |
| | 0.1% | 0.9% | 10.7% | 25.3% | 0.6% | 28.2% | 3.6% | 19.1% | 11.6% | 100.0% |
| Mining | 17 | 482 | 3,716 | 28,254 | 70 | 4,174 | 773 | 4,443 | 467 | **42,396** |
| | 0.0% | 1.1% | 8.8% | 66.6% | 0.2% | 9.9% | 1.8% | 10.5% | 1.1% | 100.0% |

# Who is innovating?

Mineral producers patent less in Mining sector

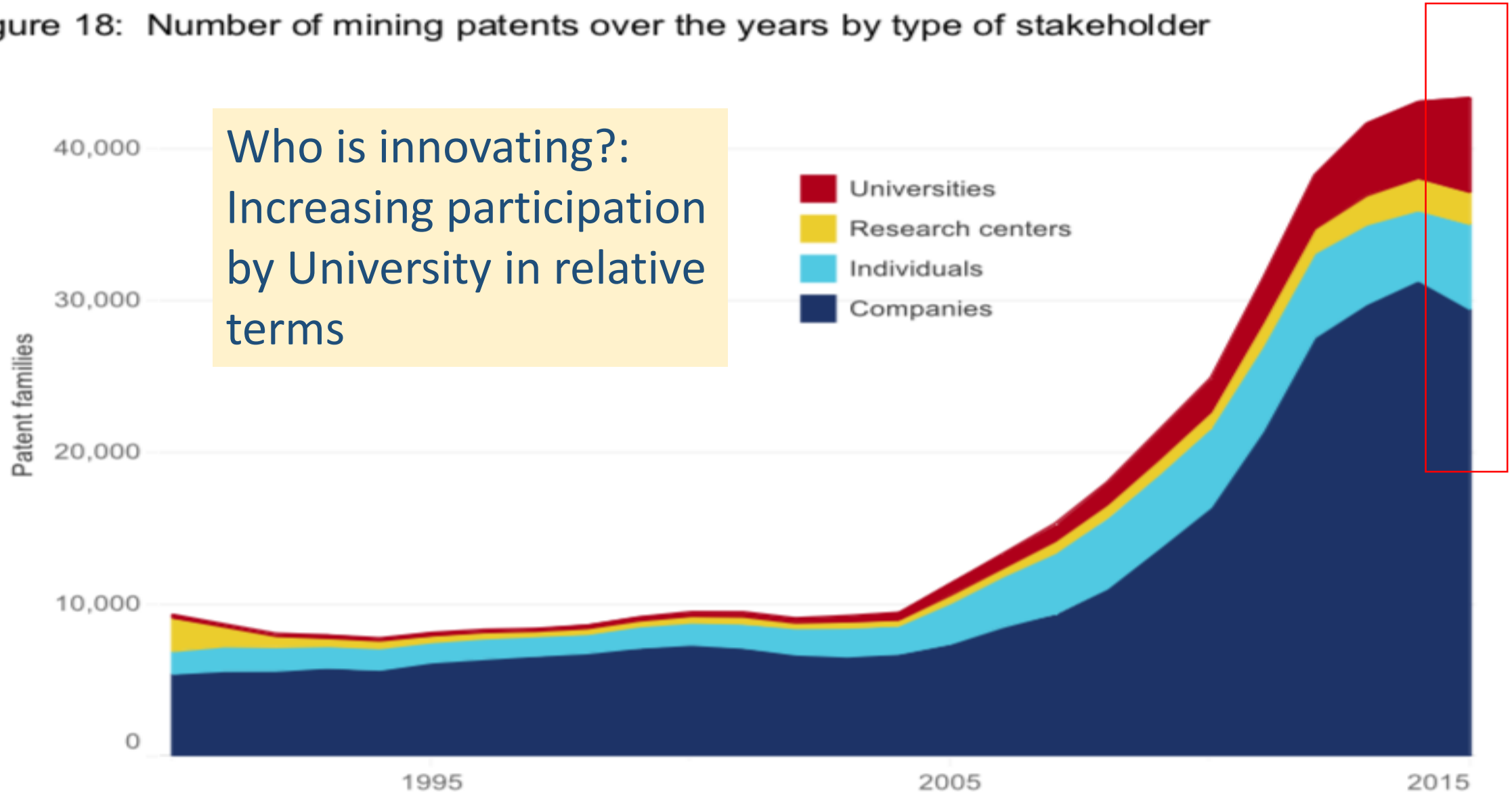
Figure 13: Mining production and innovation by country, selected countries




*Source: WIPO Mining Database (technology subset) and Reichl et al (2018). Notes: sample contains only top mineral producing and top mining patenting countries.*

Figure 18: Number of mining patents over the years by type of stakeholder

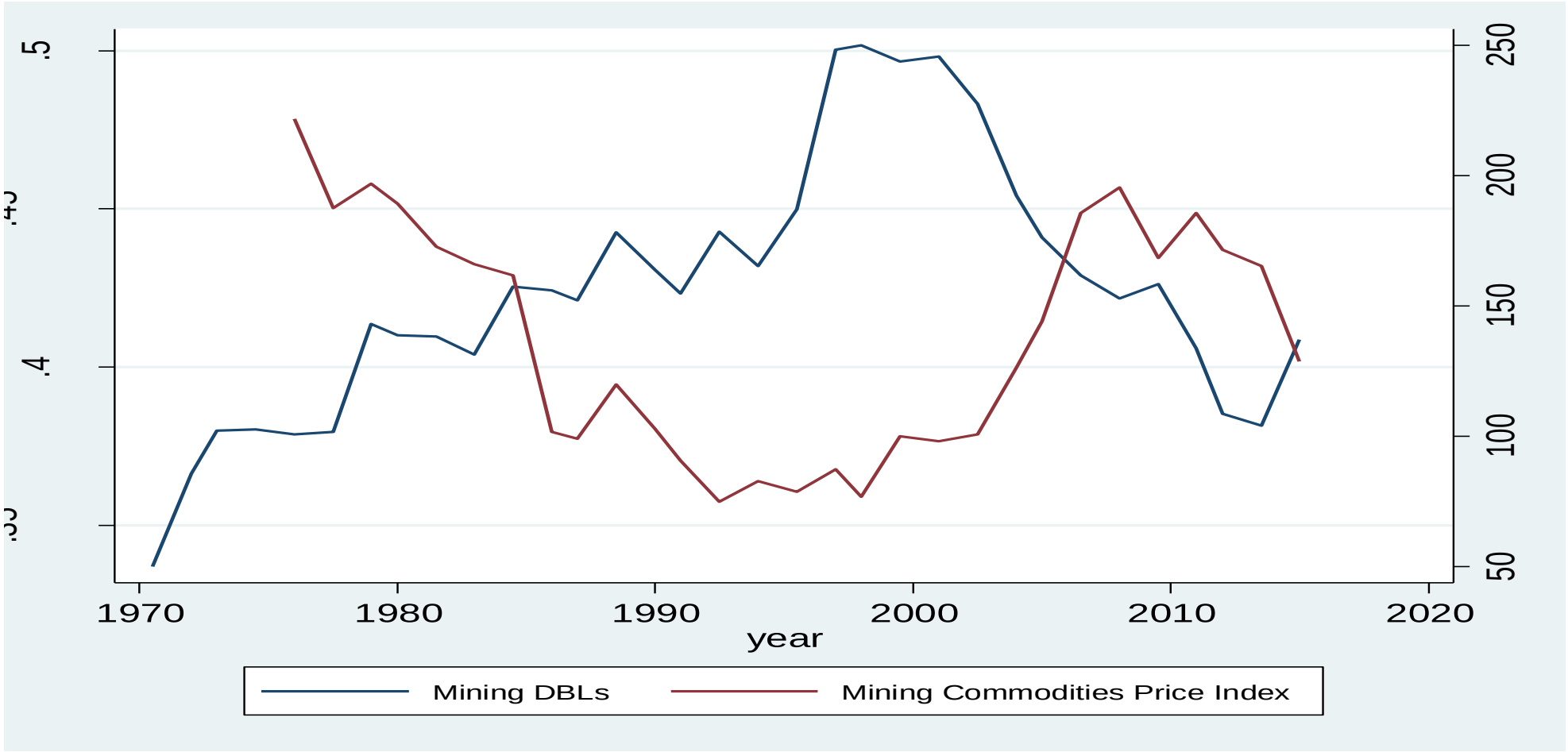
Who is innovating?: Increasing participation by University in relative terms




*Source: WIPO Mining Database (technology subset)*

# Who is innovating and when?: suppliers' contribution to value increase when mineral price goes down

## World Backward linkages and price indices in mining sector 1975-2015




**Backward linkages (use of supplier) increase when price declines**

**Backwardlinkage=reliance on supplier**

Calzada Olvera and Froster-MacGregor, 2019

# Findings

- How (Innovation take place in mining) from existing evidence?
  - When (innovation takes place?)
    - Exploration when price goes up (revenue enhancing)
    - Process innovation when price goes down (cost cutting)
  - What (kind of innovation?)
    - Improvement on finding better deposits, efficiency in extraction rate
    - Improvement in process, operation, safety, labour saving, optimization
    - Technological, Research oriented innovation, Organizational focusing on process
  - Who (innovate? And Where, which segment of value chains?)
    - Suppliers for cost reducing innovation
    - Miners for extraction  improvement innovation, explorations
    - Participation of university increased, in particular with university-company collaboration
    - Different types of collaboration may emerge (with start up, research institution for innovation)

# Conclusion

Innovation pattern in mining has some characteristics due to the nature of industry

- High risk and high return—making it long term investment on knowledge difficult but we observe increase in patenting activities since mid 2000s.
- Long term and costly investment with 20 year cycle of investment(if in scale efficiency)
- Exogenous price of commodity influence the type of innovation
- Innovation activities are concentrated in
  - Cost reduction focus
  - Embodied technology: introduction of machineries
  - Service suppliers, close collaboration with suppliers
  - Exploration, Extraction efficiency main concern of miners
  - Innovation pattern is very much influenced by mineral Price=Profit
- New emerging space for digital technology in process optimization
- Future potentials for social and environment related technologies
- Increasingly knowledge comes from outside of mining sector
- Collaboration with different partner may be needed

# Areas of consideration for policy to stimulate innovation in mining

- Creating inducive environment for good collaboration with different stakeholders  for innovation
  - Miner-supplier collaborations
  - Miner-supplier with technological start-ups
  - Miner – University collaborations
  - Mining suppliers –University collaborations
  - Other sector-Mining collaborations
- Resource mobilization, ownership of IPR, mechanisms for above collaboration
- Standardization of equipments  to facilitate upgrading of suppliers?
- Capacity upgrading of human resources and suppliers for the optimal uses of digital technology will be needed (Solow Paradox)
- Value addition of Ore through certification ?
- Lateral Migration of technology should be considered
  - In areas of contamination mitigation (Talling)
  - Providing energy and water

# Annex:
# Summary of Technological roadmap for mining sector for 2035 by Chile
# Alta Ley

# Technological roadmap by phase: Exploration and Mining development

| | Main technology | Main Companies | Main Univ. in |
|---|---|---|---|
| Exploration | Lasers, Seismology, Prospecting, Tunnels Galleries, Systems using reflection or re-irradiation of the electromagnetic waves | Caterpillar, Shell Oil Exxon mobile Upstream Resources, Foro Energy, Tech Resources, Sandvik Mining | Australia, USA, China, Chile, Canada |
| Planning | Underground and Surface mine operation | Sandvik Mining & Construction, BHP Billion Innovation, Sandvik Intellectual Property, Atlas Copco Rock Drills, | Australia |

Source: Bramber et al, 2019

# Technological roadmap by phase: Exploration and Mining development

| | Main technology | Main Companies | Main Univ. in |
|---|---|---|---|
| Operation | Drills, adopted to change directions with means for collecting substances; Manufacture of composite layers, parts or objects based on metallic dusts | Baker Hughes, Halliburton Energy Service, Kennametal, Longyer, Potter Drilling, Schlumberger technology, Smith International TDY IND | China |
| Tailing | Destruction or transformation of solid wastes, low mixers, sludge treatment, devices, water treatment | Basf, Suncor Energy, Kurita Water, Smith and Co Changchum Gold Resources, Du Pont, Fort Hills Energy, Nippon Soda, Total E&P Canada, China National Gold Group | Germany, China |

Source: Bramber et al, 2019

# Technological roadmap by phase: Comminution Beneficiation and Concentration

| | Main technology | Main Companies | Univ. Research |
|---|---|---|---|
| Grinding | Pressing adapted to specific ends, Layout of separation in the plant, Control systems adapted to crushing and disintegration, Metal working | Smidth, Unimin, Outotec, Metso Minerals France, Tech Resources, Arter Technology, KDH Humboldt Wedag | Canada, South Africa, Chile Australia |
| Crushing | Preliminary treatment of scrap, Methods or ancillary devices, Accessories adapted to crushing and disintegration | Tech Resources, Takraf, Unimin, Joy MM Delaware, Thyssenkrupp, SuncorEnergy | China, USA, Australia |
| Flotation | Flotation agent, Materials, specific applications | Barrick Gold, Basf, BHP Billion SSM Dev, Cytech Tech, Evonik Industries, Ex Tar Technologies, Geordia Pacific Chemicals, Sumitomo Metal Mining | UK, USA, Japan, Germany |

Source: Bramber et al, 2019

# Technological roadmap by phase: Processing

| | Main technology | Main Companies | Univ. Research |
|---|---|---|---|
| Smelting | Mitigation of climate change from production | Outotech, Tanaka Precious Metal, Dowa Metals&Mining, JX Nippon Mining & Metals, Precious Metals Recovery, Mitsubishi Materials, Kosaka Smelting and Refining, Nippon PgM, Outokumpu Umicore Ag | China, Japan, Brazil, USA |
| Leaching | Ion exchange, complex Chelate formed, substances | Freeport Mc Moran, JX Nippon Mining&Metals, Outotec ,Nippon Mining, Cognis IP Man, Basf, Cytec Tech, Outotec Finland | Canada, Mexico, S.Africa, China |
| Solvent Extraction | Solid waste management, Rare metals collection, Metal composites | Cognis IP Mang, Commw, Scient, Cytec Tech Freeport McMoran, JX Nippon Mining&Metals, Nippon Mining, Outotec, Porcess Res Ortech | USA, Canada, China, S. Africa, Belgium, Spain, France, Japan |

Source: Bramber et al, 2019

# Technological roadmap by phase: Refining

| | Main technology | Main Companies | Univ. Research |
|---|---|---|---|
| Refining | Obtaining copper and other metals, Solid waste management, Electrolytic Production, Recovery and refining metals via electrolysis | JX Nippon Mining&Metals, Pan Pacific Copper, Nippon Mining, Phelps Dodge, Freeport McMoran, Outotec, Xianguang Copper, Sumitomo Metals Mining | Chile, Belgium, Japan, Canada, USA |
| Electrowinning | NA | Alcan, Aluminum of America, Aluminum Corp of China, BHP Billiton, Elkem Green Metals, Moltech Invent, Pechiney Aluminum | S. Korea, USA, Canada Belgium |

Source: Bramber et al, 2019