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| Evolution of urban mobility | | | | | | Trends in automobile industry: **C**onnected - Internet of Things (IOT). **A**utonomous. **S**hared - Mobility as a service. **E**lectrification - EVs  Types of EV: 1) Battery EV (BEV): has only battery and needs to be plugged in to be charged  2) Plug-in Hybrid EV (PHEV): has both petrol engine & battery, can be plugged in to be charged  3) Hybrid EV (HEV): has both petrol engine & battery, can't be plugged in to charge (charge using braking and combustion engine)  4) Fuel Cell EV (FCEV): carries fuel in form of hydrogen gas, converted to electricity using fuel cells  Power supply -> Charging socket -> Onboard Charger -> Battery pack -> Controller -> Electric Motor (for wheels) | | | |
|  | EVs are climbing the S-curve for tech adoption. Slow growth as tech develops -> Exponential growth as prices fall -> Market saturation, growth slows  2020 < 5% EVs for global sales. 2021 9%. 2022 14%. 2023 18% (predicted). 2030 30% | | | | | | | | |
| Advantages of modern EVs over Internal Combustion Engine (ICE) vehicles | | | | | 1) Environmental: No tailpipe emissions containing CO, CO2, NOx, SOx, PM2.5,...  2) Energy: Uses electricity which can be generated by renewable energy. Regenerative breaking also partially charge battery. On a national level, reliance on imported liquid fuels is reduced  3) Efficiency: ICE = ~25-50%. Electric motors = ~ 90%  4) Mechanical: EV drivetrain has fewer moving parts (~20) than ICE (~2000) => less maintenance. Also more silent  5) Performance: Superior acceleration than ICE cars. 6) Technology: Over the air auto update of software, autonomous driving  7) Space: room is freed at the front ("frunk")  But Energy density (amt of energy stored per unit mass (gravimetric) or per unit volume (volumetric) of petrol is > than batteries | | | | |
| History | | | | 20th century in US: cars could be propelled by steam, petrol and electric  Ford Model T (1908-1927): 1) Performance: Petrol cars could travel further and faster than electronic cars running on lead-acid batteries  2) Resource supply: Vast petroleum deposits found in Texas, Oklahoma and California  3) Engineering improvement: First car to be manufactured by moving assembly line, reduce cost due to economies of scale. Thus Model T was 50% cheaper than electric cars | | | | | |
| Largest automakers in 2022 | | | | | | | | Largest car manufacturers by car sales (mostly ICE cars): 1. Toyota (9.55 million). 2. Volkswagen. 3. Hyundai Kia. 4. Stellantis. 5. GM  Largest BEV manufacturers: 1. Tesla (1.3 million). 2. BYD (include PHEV also). 3. SAIC. 4. Volkswagen. 5. Geely | |
| First modern mass-produced BEW | | | | | | | | GM EV-1 available for lease from 1996-1999. 60-90 miles on full charge (didn't use lithium-ion battery). Got scrapped due to high build cost and low customer base. | |
| History | | | 1991: Rechargeable Lithium ion batteries (LIBs). 2019: Nobel Prize in Chemistry on LIBs  2000s - Entrance of all electric and hybrid vehicles from startups and incumbent  - Tesla: Founded in 2003. First product = Tesla Roadster (2006). First highway legal serial production all electric car using lithium-ion battery cells. First to travel > 320 km (200 miles) per charge  - Fisker. - BYD: Batter maker w vehicle division founded in 2002. World first production PHEV, F3DM (2008)  - Nissan: Nissan Leaf (2010) best selling EV till 2019. - Toyota: Toyota Prius (1997) world first mass-manufactured hybrid | | | | | | |
| Tesla | | Aesthetics and UX similar to Apple ecosystem. Car as a tech platform - Software Defined Vehicle (SDV) E.g. over the air updates for software, autopilot, full self-driving (FSD), flush door handles, superchargers and magic dock  High degree of vertical integration, i.e. supercharging network (traditional car makers don't operate petrol stations)  Non-traditional sales, service & marketing model (no car dealership/middleman for sales, minimal ads, vehicle insurance based on driving data)  Tesla Roadster (2008) - Sports car - High price, low volume. Tesla Model S (2012) - luxury sedan - mid price, mid volume  Tesla Model 3 (2016) - Sedan for the masses - low price, high vol. 2/3 of all EVs in North America made by Tesla (2021) | | | | | | | |
| China | | 2010s - emergence of China as world no 1 EV market. Currently half the total num of EVs in the world are in China.  Result of aggressive govt support for EV industry, "new energy vehicles" (NEV) on both supply and demand side since 2009  Subsidies for purchase, Priority of parking permits.  World's largest LIB manufacturer - CATL in China. Many Chinese EV companies, BYD, Xpeng, NIO, SAIC, Geely  Traditional automakers (Volkswagen, Ford, GM, Toyota) trying to fight back now | | | | | | | |
| Barriers to EV adoption | | | | 1) Range anxiety: problem w long-dist travel. 200 miles (322km) now a typical range  2) Availability and time needed for charging: More charging stations and superchargers being built. Supercharger can charge 80% of typical EV in ~ 30 mins or less  3) Cost: Prices expected to drop further as economies of scale for car and battery manufacture are achieved and more EVs offerings by diff auto companies. Total cost of ownership for EVs  4) Customer perception of quality and safety: Upcoming Solid-state LIBs will improve inherent safety of LIBs | | | | | |
| Govt policy and regulations | | | | | | | Role of laws and regulations. Rold of subsidies and taxes in encouraging EV/discouraging ICE vehicles  Develop EV supply chain. Develop public charging networks. | | |
| SG | | | | | | Blue SG EV rental cars (2017). Re-entry (2021) of Tesla. Commitment by govt to have 60,000 chargers by 2030.  By 2040, all cars must run on cleaner energy. Production of Hyundai Ioniq EVs in Tuas. Additional Registration Fee (ARF) waived for EVs. Half of SG public bus fleet (~5800 in 2022) will be electric by 2030 | | | |
| Choice under scarcity | | | | | | Scarce = insufficient to satisfy needs or wants. Not enough in quantity compared w demand  Individuals: money, time. Society: Labour, physical capital and human capital, land and natural resources, entrepreneurship | | | |
| 5 core principles of economics | | | | | 1. Scarcity implies Trade-Offs. 2. Bargaining Strength comes through scarcity. 3. Compare costs and benefits. 4. Ppl respond to changes in costs and benefits. 5. Focus on your comparative advantage  1. Unlimited wants, limited resource. Having more of one thing usually means having less of another (economic growth vs emissions)  2. Scare resources command high prices. (key metals like Li, Co, Ni, Cu, Al, Mn, P required in LIB)  3.Take action iff benefit is at least as great as the cost. (buying EV, consider if benefits gain over lifespan of car exceeds cost of ownership)  4. Likelihood of taking an actions rises as benefits rises and falls as cost rises (Subsidies to buying EV)  5. Everyone gains when each individual/country focus on activies in which one can produce at a lower cost than anyone else (China dominance in battery production) | | | | |
| Opportunity Cost | | | | | | Compare costs and benefits of alternative choices. Opp cost of action X = explicit cost of X + implicit cost of X  Explicit cost = cost of X indep of attr of any alternative to X (money). Implicit cost: value of best forgone alternative   |  |  |  |  | | --- | --- | --- | --- | |  | X | Y | Z | | Explicit cost in $ (EC) | 50 | 50 | 30 | | Value of benefit in $ (VB) | 70 | 60 | 55 | | VB - EC | 20 | 10 |  |   Implicit cost of Z = max{(70-50), (60-50)} = max{20, 10} = 20. Opp cost of Z = explicit + implicit cost = 30 + 20 = 50  Since opp cost = 50 < 55 = benefit of Z -> take action Z | | | |
| How to integrate ideas from economics into study of BEVs | | | | | | | | | Climate changes imposes ecological end economic cost -> policies to reduce emissions -> EVs revolution in urban mobility |

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| Changes in Global Supply and Demand of Commodities | | | | | | 4. Ppl respond to changes in costs and benefits: Changes in Global Supply and Demand of Lithium -> Changes in Price of Lithium -> Changes in Investment in Technology & Substitutes -> Changes in Global Supply and Demand of Lithium | | |
| Markets | A market is a grp of buyers and sellers of a particular good or service. In perfectly competitive markets: goods & services are practically identical. Buyers and sellers are so numerous that no one can affect the market price – everyone is a price taker  Economists use supply and demand model. (Simple: initial knowledge required to make prediction is little & Fruitful: the more precise the prediction, the wider the area within which the theory yields prediction) | | | | | | | |
| Quantity demanded: amt of good that buyers are willing and able to purchase  Law of demand: other things equal (ceteris paribus), price of good inversely related to quantity demanded of good  Demand: r/s btw price of a good and quantity demanded. Demand curve: graph w price on vertical axis & quantity on the horizontal axis  Individual demand: max amt one is willing to pay for the product  Quantity demanded in the market = sum of quantities demanded by all buyers at each price | | | | | | | |
|  | Change in price causes a movement along the D curve  Non-price determinants of demand (causes demand curve to shift): num of buyers, income, price of related goods, tastes, expectations | | | | | | | |
|  | Quantity supplied: amt of good that sellers are willing and able to sell  Law of supply: other things equal (ceteris paribus), price of good directly related to quantity demanded of good  Supply: r/s btw price of a good and quantity supplied. Supply curve: graph w price on vertical axis & quantity on the horizontal axis  Individual supply: min amt a firm is willing to sell for the product  Quantity suppplied in the market = sum of quantities supplied by all buyers at each price | | | | | | | |
|  | Changes in prices causes a movement along the S curve  Non-price determinants of supply (causes S curve to shift): num of sellers, input prices (wages, cost), technology, weather, expectations | | | | | | | |
| Equilibrium | | | A graph of a graph of a graph  Description automatically generated with medium confidencePrice, P has reached the level where Quantity supplied = Quantity demanded, QS = QD = Q\*.  P\* = equilibrium price, Q\* = equilibrium qty traded in the mrkt  If QD < QS: price will fall. If QS < QD: price will rise  Due to principle of voluntary exchange, both sides should not be worse off after the trade  Assume all agents are rational  Prices play key role in allocation of resources, by providing signals to which buyers and sellers respond  Combined action of buyers and sellers determines the mrkt forces of supply and demand, moving prices towards equilibrium | | | | | |
| Measuring Market Efficiency | | | A yellow and blue triangle with black lines  Description automatically generatedConsumer Surplus (CS) = amt buyer willing to pay - amt actually pays (buyers' gains from participating in the mrkt)  Producer Surplus (PS) = amt seller is paid - cost (sellers' gains from participating in the mrkt)  Total Surplus (TS) = CS + PS (total gains from trade)  Allocation of resources is efficient if it maximizes total surplus  If buyer WTP (willingness to pay) is ≥ P\* will pay, if < P\*, won't buy -> buyers w highest valuation are the ones who consume the good  If seller whose cost is ≥ P\* will not sell, if < P\*, will sell -> sellers w lowest cost are the ones who produce the good  Q\* maximizes total surplus, i.e. society's well being is maximized | | | | | |
| First Fundamental Theorem of Welfare Economics | | | | Assume that : 1. There are mrkt and mrkt prices for all goods. 2. All buyers and sellers are competitive price-takers  3. Each person's valuation of a good (utility) depends only on one's own consumption of the good  Then any mrkt equilibrium is efficient | | | | |
| Market Failure | | If any of assumptions don't hold, then "Mrkt equilibrium is efficient" may not be true. E.g.  1. Mrkts not perfectly competitive, i.e. buyer or seller has mrkt power – ability to affect/control mrkt price  2. Transactions have externalities: side effects that affect bystanders, (prices do not reflect true cost to society) | | | | | | |
| Externalities | | | By-product of consumption or production. Affect someone other than buyer or seller.  Social costs and benefits = sum of private and external costs and benefits  Self-interested buyers and sellers consider only the private costs and benefits of their actions; neglect external costs or benefits of their actions -> mrkt outcome not efficient | | | | | |
| Negative externalities  E.g. pollution, second-hand smoke | | | A graph of a price  Description automatically generatedMrkt equilibrium only maximizes CS & PS. Supply curve shows private cost. Demand curve shows private value  Social cost = private cost + external cost. External cost = impact on bystanders = $1 per litre in this e.g.  At any Q < 20, value of additional litre exceeds social cost  At any Q > 20, social cost of the last litre is greater than its value to society  Mrkt equilibrium: Q = 25. Social optimum: Q = 20  To solve: "Internalizing" the Externality: Impose tax on sellers to make sellers' cost = social cost  -> mrkt equilibrium = social optimum  Imposing tax on buyers would also achieve the same outcome  This works as *People respond to changes in costs and benefits* | | | | | |
| Positive externalities | | | | | Social benefit = Private benefit + external benefit. E.g. being vaccinated protects others around you, R&D, education | | | |
| Public policies toward externalities | | | If -ve externality, mrkt qty > socially desirable. If +ve externality, mrkt qty < socially desirable  1. Command & control policies: regulate behaviour directly (e.g. limit num of COE, require firms use a particular tech to reduce emissions)  2. Mrkt-based policies: provide incentives so that private decision-makers will choose to solve problem on their own (e.g. subsidies and taxes, tradable pollution permits) | | | | | |
| Private solutions to Externalities | | | Moral codes and social sanctions. Charities. Contracts btw mrkt participants and affected bystanders  Coase Theorem: If private parties can bargain, w/o cost, over the allocation of resources, they can solve the externalities problem on their own. Whatever the initial distribution of rights, interested parties can reach a bargain: Everyone is better off & Outcome is efficient  i.e. private mrkt achieves efficient outcome regardless of initial distribution of rights  Colin chemical plant emission affect Denise health. Socially efficient outcome = Maximizes Colin's well being + Denise's well being | | | | | |
| X has legal right to emit polluting smoke  Benefit to X to run plant = $500  Cost to Y health = $800  Socially efficient outcome: Stop plant  Private outcome: Y pays X $501 to stop operating plant  Private outcome = efficient outcome | | | | X has legal right to emit polluting smoke  Benefit to X to run plant = $1000  Cost to Y health = $800  Socially efficient outcome: Plant continue  Private outcome: Y not willing to pay > $800. X not willing to accept < $1000  Private outcome = efficient outcome | Y has legal right to clean air  Benefit to X to run plant = $800  Cost to Y health = $500  Socially efficient outcome: continue  Private outcome: X pays Y $501 to put up w plant emission  Private outcome = efficient outcome |
| Why private soln don't always work | | | 1. Transaction costs: costs incur in the process of agreeing to and following through on a bargain  2. Stubbornness: Even if beneficial agreement is possible, each party may hold out for a better deal  3. Coordination problems: If num of parties is very large, coordinating them may be costly, diff, or impossible | | | | | |
| Taxonomy of Goods | | | |  |  |  | | --- | --- | --- | |  | Rival | Not Rival | | Excludable | Private Good: hamburger | Club Good (Natural Monopoly): cable TV | | Not Excludable | Common Resource: fishes in ocean | Public Good: natural defence |   Excludable: person can be prevented from using it  Rival in consumption: one person's use of it decr other ppl use of it | | | | | |
| "Priceless" Goods | | | Not excludable goods = people cannot be prevented from using them, i.e. available to everyone FOC -> No prices attached to these goods  -> mrkt forces that allocate resources based on price is missing -> private mrkt may fail to provide socially optimal qty -> govt intervention | | | | | |
| Public Goods & Govt | | | Since public goods are not excludable & not rivalrous, people have incentive to be free riders (person who receives the benefits of a good but avoids paying for it) -> firms do not produce good  Free-rider problem -> mrkt failure -> Govt can use tax revenue to supply that good IF benefit of public good > cost of providing it | | | | | |
| Common Resource & Govt | | | Common resources are not excludable -> Free riders cannot be prevented from using them -> Firms dont produce -> Govt has to provide  Common resources are rival in consumption -> each person's use reduces others' ability to use it -> Govt has to ensure goods are not overused, i.e. is used sustainably | | | | | |
| Tragedy of the Commons | | | Illustrates why common resources are overuse (e.g. overfishing and climate change)  Mrkt participants need to find a way to align individual incentives w goals of the group (tradable permit system, carbon tax)  Policies to prevent overconsumption of common resources: - Privatize the resource (convert land to private good -> make resource excludable)  - Regulate use of resource (Beijing's license plate policy -> regulate private behaviour)  - Impose corrective tax (hunting and fishing license, entrance fees for national parks -> eliminate free rider)  - Auction off permits allowing use of resouce (EM frequency spectrum -> help define property rights and hence unleash mrkt forces) | | | | | |

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| Physics | | Battery = device that converts chemical energy to electrical energy. Is a self-contained source of energy (compared to diesel generator)  Primary batteries (AA battery) = cannot be reused as chemical energy is exhausted after single use  Secondary batteries (Lithium ion batteries) = can be recharged and reused, but can only be used for a fixed num of cycles (cycle life)  In EV, Li-ion battery is 400V. ICE vehicle also has a low voltage lead-acid battery for power locks, wipers, headlights, ... |
| A diagram of a graph  Description automatically generatedAC = alternating current (from electrical mains). DC = direct current (from batteries)  DC can be converted to AC using an inverter.  In SG, electrical mains are 230V, 50 Hz (frequency, no. of cycles a second, Hz = s-1)  230V ≠ highest voltage, but average of sine curve  Fundamental Constant: charge of 1 electron = 1.602 \* 10-19 C |
| |  |  |  |  | | --- | --- | --- | --- | | Voltage | Diff in electrical potential btw 2 points | Volt [V] | Energy [J] / Charge [C] | | Current | Rate of flow of charge | Ampere [A] | Charge [C] / Time [s] | | Capacity | Measure of charge stored in battery or electrode | Ampere-Hour [Ah] or Coulomb [C]  1 Ah = 3600 C | Current [A] \* Time [h] | | Power | Dissipation of energy over time | Watts [W] | Energy [J] / Time [s] or  Current [A] \* Voltage [V] | | Energy | Ability to do work  Units: V \* A \* s = J OR V \* Ah = Wh | Watt-Hour [Wh] or Joules [J]  1 Wh = 3600 J | Power [W] \* Time [h] or  Voltage [V] \* Capacity [C] | |
| Chemistry | | Chemistry aims to synthesize useful molecules and materials via chemical reactions which can be described by chemical equations  - Redox equations (a type of chemical equation) = when electron transfer occurs (which happens in batteries)  Factors to consider: Is chemical reaction spontaneous (thermodynamics)? How fast does it occur (kinetic) |
| Periodic Table | | A periodic table of metals  Description automatically generatedIn a box, from top to bottom: atomic number (num of protons); atomic symbol; atomic weight (g/mol)  - Groups: vertical columns (based on num of valence electrons = electrons in outer shell)  - Periods = horizontal rows  - Elements can be divided into metals, non-metals & metalloids  - Metals form positively charged ions (cations) via loss of electrons  - Non-metals form negatively charged ions (anions) via gain of electrons (Cl-, NO3-, SO42-)  - Ionic compound has formula containing cations & anions written sequentially and is charge neutral |
| NaCl | | A diagram of a molecule  Description automatically generatedSodium Chloride is tha main constituent of table salt  At room temperature, where it is a solid, the structure consist of Na+ and Cl- packed in a regular pattern (crystal lattice). So NaCl at room temperature is more accurately described as (Na+Cl-)n where n is a large number, but not a convention to use this. |
| Chemical Equations | | Chemical equations: Reactants -> Products. There should be no free charges/electrons  Zn(s) + 2HCl (aq) -> ZnCl2 (aq) + H2 (g) (s: solid, aq: aqueous, g: gas, l: liquid)  Neutralisation reaction: acid + base -> salt + water: H2SO4 (aq) + 2NaOH (aq) -> Na2SO4 (aq) + H2O (l) |
| Ionic equation | | Chemical equations that occur in solution can be simplified to ionic equations by eliminating spectator ions  Chemical eqn: Zn(s) + 2HCl (aq) -> ZnCl2 (aq) + H2 (g). Rewrite to individual ions: Zn (s) + 2H+ + 2Cl- -> Zn2+ + 2Cl- + H2  Ionic eqn: Zn (s) + 2H+ (aq) -> Zn2+ (aq) + H2 (g) |
| Redox eqn | | Redox eqn = Chemical eqn where there electron transfer btw the reactants (e.g. Zn (s) + 2H+ (aq) -> Zn2+ (aq) + H2 (g))  Redox eqn can be broken down into 2 half eqns. Each half eqn contain either a loss OR gain of electrons only. Loss and gain must balance  Oxidation (loss of electrons): Zn -> Zn2+ + 2e-. Reduction (gain of electron): 2H+ + 2e- -> H2  Battery chemistries are always redox equations. The 2 half reactions (oxidation and reduction) must occur in separate compartments, and the separate compartments must remain in contact through an ionic solution (electrolyte) and a wire (for electrons to flow) |
| Electro-chemical cell | Diagram of a diagram of a copper electrode solution  Description automatically generatedAn electrochemical cell has two electrodes and electrolyte. An electrode is an electrical conductor that is in contact with the electrolyte and where electrons are gained or lost.  Here Zn metal and Cu metal are the electrodes  Voltaic/galvanic cell is an electrochemical cell that uses a spontaneous chemical reaction to produce electrical energy.  Strictly speaking, a battery consists of many voltaic cell, but they are used interchangeably.  Oxidation half cell eqn: Zn (s) -> Zn2+ (aq) + 2e-. Reduction half cell eqn: Cu2+ (aq) + 2e- -> Cu (s)  Net redox eqn: Zn (s) + Cu2+ (aq) -> Zn2+ (aq) + Cu (s)  Anode = electrode where oxidation takes place (zinc)  Cathode = electrode where reduction takes place (copper)  Both electrodes are immersed in the electrolyte, which consists of ions. Electrolyte completes the circuit. | |
| The Voltage (V) read by the voltmeter = cell potential Ecell or open-circuit voltage (Voc).  If the conditions are standard, it is referred to as the standard cell potential, E0cell. For this system it is +1.10 V  Standard condition = temp of reaction is assumed to be 25, concentration of aqueous reactants & products is 1 M, pressure = 1 atm  For a battery chemistry which is spontaneous, its Ecell > 0 = discharging  When a load with resistance is connected across the electrodes, electrons flow in the external circuit (from -ve to +ve) and do work, i.e. light the lamp. Ions move in the electrolyte  Salt bridge = to complete the circuit and maintain electrical neutrality | |
| Zn-MnO2 alkaline battery | | Common AA primary battery chemistry. Overall equation: Zn + 2MnO2 → ZnO + Mn2O3  Electrodes: Zn, MnO2 (manganese dioxide) Electrolyte: KOH (potassium hydroxide)  Half cell equations: (oxidation) Zn + 2OH- → ZnO + H2O + 2e- (reduction) 2MnO2 + H2O + 2e- → Mn2O3 + 2OH- |
| Maximum Theorectical Specific Energy (MTSE) | | One can calculate the theoretical maximum specific (gravimetric) density of a particular battery chemistry  MTSE = how much energy is contained per unit weight of battery chemistry. Can be used for comparison btw diff chemistries  MTSE = (in Wh/kg), where n = num of electrons transferred per mol according to half eqn. F = Faraday Constant (96,485 C/mol)  E = average or nominal voltage of the battery (in Volts) and will be given to you. E > 0 = eqn is for discharging  FW = formula weight(sum of atomic weights) of the *reactants* according to the chemical eqn  This value is the theoretical maximum as it ignores the weight of everything else (i.e. weight of electrolyte) except the reactants |
| E.g. | | For Zn-MnO2 battery, given E = 1.5V: (voltage \* capacity = energy in joules)  MTSE = n \* F \* E / (FW of Zn + FW of 2MnO2) = 2 \* 96485 \* 1.5 [J]/ (65.409 + 2\*(54.938 + 2\*15.999)) [g] = 289455/ 239.281 [J/g]  = 80.4 Wh/ 0.239 kg = 336 Wh/kg |
| Rechage-able battery | | A rechargeable battery = secondary battery. It can be discharged and then charged for some time with no appreciable loss in performance  Environmentally friendly since less batteries are disposed. Lithium ion battery = newest rechargeable battery. Oldest = lead-acid battery (currently used in ICE cars). Lithium-ion battery first commercialized in 1991 by Sony for video camcorder  - In order to achieve the best energy/weight ratio, a light metal (gravimetric energy density) is required. The lightest metal with molecular weight 6.94 g/mol is Li. It has Strong reducing power, i.e. Li wants to give away its one valence electron in its outer shell  Discharging is an energetically spontaneous even as electrons flow from a higher to lower energy level. |
| Early Lithium-ion batteries (LIBs) | | A diagram of a structure  Description automatically generated with medium confidenceUsed metallic lithium as one of the electrodes. Overall equation: Li + TiS2 LiTiS2  Half equations for discharging: (oxidation) Li → Li+ + e-. (reduction) TiS2 + Li+ + e- → LiTiS2  A diagram of different types of discharge  Description automatically generatedHalf equations for charging (oxidation) LiTiS2 → TiS2 + Li+ + e- . (reduction) Li+ + e- → Li  Discharge - dissolution of Li(s): Li(s) → Li+ + e-  Charge- plating of Li(s): Li+ + e- → Li(s)  Dendrites are the main reason why pure lithium electrodes are still not feasible, creates short circuits btw cathode and anode |

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| Modern LIBs | | | Modern LIB must always be charged first (not needed for early LIBs) as it is assemble in the uncharged state  Overall eqn: 2LiCoO2 + 6C 2Li0.5CoO2 + LiC6 (LiCoO2 = Lithium Cobalt Oxide)  Charging: 2LiCoO2 + 6C → 2Li0.5CoO2 + LiC6. Discharging: 2Li0.5CoO2 + LiC6 → 2LiCoO2 + 6C  LIB is assembled using LiCoO2 and C in the uncharged state. A LIB is always delivered to the customer charged | | |
| Half eqns for charging: (oxidation) 2LiCoO2 → 2Li0.5CoO2 + Li+ + e-. (reduction) 6C + Li+ + e- → LiC6  Half eqns for discharging: (oxidation) LiC6 → 6C + Li+ + e-. (reduction) 2Li0.5CoO2 + Li+ + e- → 2LiCoO2  Charging: Anode = LiCoO2 (+ve side of battery), electrons → Cathode = Graphite (C) (-ve side of battery)  Discharging: Anode = LiC6 (-ve side of battery), electrons → Cathode = Li0.5CoO2 (+ve side of battery)  Note: you can charge LiCoO2 to Li0.9, Li0.8, …, Li0.5CoO2. Further removal of Li leads to safety issues due to overcharging | | |
| LIB | | | A diagram of a battery  Description automatically generatedPositive and negative electrodes used to refer to LiCoO2 and C since identity of cathode and anode changes w charging and discharging  Charge: positive electrode = anode, and negative electrode = cathode.  Discharge: positive electrode = cathode, and negative electrode = anode.  Positive electrode: Layered structure compounds, i.e. LiCoO2 and related LiMO2 compounds, OR other compounds, i.e. LiFePO4  Negative electrode: Graphite/graphitic (C) materials OR Lithium metal (still in research)  Electrolyte: Liquid electrolytes - organic solvent w lithium salt (LiPF6) added to improve ionic conductivity. (Note water cannot be used for solvent)  Note in real world, LiCoO2 is commonly referred to as cathode and C as anode w/o referring to whether it is being charged or discharged. Which is not scientifically consistent. | | |
| C-rate | | | A diagram of a charge current  Description automatically generatedTerm used to measure speed at which a battery is fully charged or discharged  Charging at a C-rate of 1C means battery is charged from 0-100% in 1h. 3C rate is 3 times faster, so time for full charge = 20 mins  Charging at high C-rates typically increases rate of degradation of battery and may cause dendrites to form  To charge LIBs:  1) Constant current (CC) till target voltage ≈ 4.1 - 4.2V. Battery ≈ 80% charged at that time  2) Followed by Constant voltage (CV) w decreasing charging current (to prevent overcharging) which is slower  3) Charging is stopped when a preset min current is reached | | |
| Recharging of LIBs (CC/CV) | | |
| Formats of LIBs | | | A close-up of several batteries  Description automatically generatedEach format has its own merits and is selected according to application and design requirements. Cylindrical, Prismatic and Pouch formats are used in EVs (manufacturer dependent) | | |
| Terms | Cells  Module  Battery Pack | | | | Basic unit of a LIB that exerts electric energy by charging & discharging. Made by inserting cathode, anode, separator, current collector and electrolyte into a casing  A battery assembly put into a frame by combining a fixed num of cells to protect the cells from external shocks, heat or vibration  Final shape of the battery system installed to an EV. Composed of modules and various control/protection systems including a Battery Management System (BMS), cooling system, etc |
| Cylindrical cell | | | Swiss roll structure, i.e. sheet electrodes and sesparator (plastic sheet) are rolled up and put into a steel can. All these layers are very thin ~ 10-50 m.  For a Tesla battery pack, it consists of thousands of individual cylindrical cells wired tgt in parallel and series.  For Tesla Model S Plaid: 72 individual cells connected in parallel to form a brick, 22 bricks connected in series to form a module, 5 modules connected in series to form a battery pack.  Electricity mobility applications, (e.g. EVs) are responsible for the huge increase in battery demand now and the future | | |
| Positive Electrode | | | A diagram of a structure  Description automatically generatedLayered LiMO2 Materials, where M = Co, Mn, Fe, Ni, Al, ...  To lower cost and/or tune performance, multiple metals are used for M, i.e. LiNi0.8Mn0.1Co0.1O2 (NMC) or 811 (Note atomic fraction of Ni + Co + Mn = 1)  LiCoO2 (LCO): LiCoO2 Li0.5CoO2 + 0.5Li+ + 0.5e-  First commercialized by Sony  (+) Excellent structural stability for charge/recharge on extracting a max of 0.5 Li per formula unit  (+) LCO type batteries have higher gravimetric energy density compared to LFP  (-) Co is toxic and expensive | | |
| A diagram of a crystal structure  Description automatically generatedA diagram of a crystal structure  Description automatically generatedLithium iron phosphate (LFP): LiFePO4 : LiFePO4 FePO4 + Li+ + e-  (+) Use of earth abundant Fe instead of Co  (+) 1 Li+ per formula unit compatered to LiCoO2  (+) Much safer electrode than LiCoO2 w regards to thermal runaway  (-) Ionic conductivity of LFP is lower than LCO  (-) Needs to be synthesized in air-free atmosphere compared to LCO  NUS Internal Shuttle use BYD B12 and Zhongtong N12 models. Older BYD C9 has 324 kWh LFP battery | | |
| Negative electrode | | | A diagram of a grid  Description automatically generatedA diagram of a structure of lic  Description automatically generatedCarbon. (Charge) Li+ + 6C + e- → LiC6. (Discharge) LiC6 → Li+ + 6C + e-  - Graphite is a form of carbon used as LIB electrodes  - 2 dimensional sheets of carbon w hexagonal rings  - Graphite can be natural (mined) or made artificially using petroleum byproducts | | |
| Electrolyte Solvent & Thermal Runaway | | | A group of chemical formulas  Description automatically generatedA group of chemical formulas  Description automatically generatedElectrolyte is a mixture of (i) an organic solvent, usually a blend of carbonates (i.e. EC + DEC or DMC) and (ii) lithium salt (LiPF6)  The solvent is a good solvent of the lithium salt  A group of chemical formulas  Description automatically generatedA group of chemical formulas  Description automatically generatedOrganic solvents are highly flammable. LIBs uses organic solvents compared to water- based for other chemistry such as lead acid battery  There is finite chance that LIBs can fail with smoke, fire and even explosion due to thermal runaway  Rate of a chemical reaction (kinetics) increases exponentially with temperature. Heat originating from internal reactions will increase the rate of chemical reactions. As the chemical reaction proceeds, more heat is generated which increases rate of reaction => uncontrollable release of energy | | |
| Thermal Runaway & Causes | | | Extreme rate of temperature rise a characteristic of thermal runaway for LIBs  Thermal stability of cathodes (starting from most safe): LFP > NMC > LCO/NMC (blended cathode)  1) The initial heat generated leading to thermal runaway is often caused under abusive conditions which can be accidental or intentional  - thermal (overheating), - electrical (overcharge, high pulse power), - mechanical (crushing, internal or external short circuit)  2) Poor battery design and manufacturing defects (i.e. Samsung Galaxy 7)  3) The LIB is most dangerous when it is charged  4) For EV battery packs, addition factors need to be considered such as vehicle accidents (collisions with other cars and with surroundings) and the piercing of battery pack from foreign ground objects | | |
| EV fires | | Thermal runaway from a single LIB cell can release toxic gases and fumes from decomposition of electrolyte solvent and salt, separator, electrodes, along with fire  EV with thousands of cells is even worse as there is a prob one cell will fail, thermal runaway spreading to other cells and there are other flammables in the vehicle such as the car seats as well!  EV traction fires also hard to extinguish as the battery pack is located at base of vehicle. Note: traction fire = origin of fire is a thermal runaway  Re-ignition risks: When the issue from one cell is resolved, another cell might catch fire again. | | | |
| Safety in EV battery packs | | A diagram of safety zone  Description automatically generatedEV pack must be kept within the safety zone for safety and longevity of the battery pack  Case study Tesla Roadster (combines cell and pack level protection w redundancy features):  1) Cell level:  - Positive temperature coefficient (PTC): Each cell has an internal PTC current limiting device. (high resistance at high temp) PTC limits short circuit current on an individual cell level  - Current Interrupt Device (CID). Each cell in Tesla Roadster has an internal CID. Protect cell from excessive internal pressure (typically during battery failure) by breaking and electrically disconnecting the cell.  2) Pack level  - BMS controls and monitors battery to keep it within safe operating limits  - Liquid cooling system which keep all cells to required temperature range (typically 20-40 )  - Sensors: If sensors detect abnormal levels of smoke, humidity, moisture / abnormal inertia acceleration (due to crash) / vehicle orientation (due to rollover), battery system will disconnect.  - Fuses that protect against sudden current surges due to short circuits. | | | |
| Battery Management System (BMS) | | | | A blue square with white text  Description automatically generatedBMS is the brain of a battery pack. Electronic system that keeps the battery pack within its safety zone and operating reliably/efficiently  Monitors and process parameters associated w the battery pack and individual cells to output faults/status, control and communication (i.e. during charging) signals | |
| State of Charge (SOC) & State of Health (SOH) | | | | SOC (%) = ratio of remaining charge (capacity) in the battery, devided by the max charge (Qmax) that can be delivered by the battery  SOC = 100 \* (Q/Qmax) (battery level indicator of phone shows SOC)  SOH (%) = ratio of current battery charge (capacity) to its rated capacity (Cr) when it is freshly manufactures. A description of cell aging  SOH = 100 \* (Q/Cr)/ i.e. Qmax can decrease over time if SOH decreases.  Tesla Model 3, Tesla Model Y, BYD Atto 3, Polestar 2 have 70% SoH battery pack warranty for 8 years, 192000/160000km | |
| EV fires | | | Based on global EV battery fires from 2010-2020, 0.0012% chance of an EV traction fire. For ICE vehicles, it is ~0.1% chance  However, EV fire may reach up to 2760 compared to 815 for ICE  Water is most effective way to extinguish EV fires, at least 4000 litres of water needed.  If location and time allows, best practise is to allow EV fire to burn out by itself | | |
| Tech advancement: Solid-state electrolyte | | | | - Current electrolyte based on organic carbonates are liquids/gels that are flammable which impacts on safety of EVs  - A solid electrolyte which conducts Li+ but not electrons will solve the safety problem, i.e. Li10GeP2S12  - In contrast, the electrodes in LIB are both electron and ion conducting  - Main problems w Solid electrolytes (under research for a long time) are: 1) cost 2) performance at low temp 3) mass manufacturing  - A commercially secretive area, but Nissan and Toyota are anticipated to produce EVs with solid state electrolyte some time after 2025. | |
| Tech advancement: Sodium ion battery | | | | - Na is cheaper than Li as it is more readily available. Since in an LIB, up to 50% of costs is due to positive electrode  - Less sustainability issues compared to lithium mining  - Subject of intense research over the years, issue is finding the right combination of positive, negative electrode and electrolyte  - In 2021, CATL unveiled the first commercial sodium ion battery  (-) Lower gravimetric energy density than LIB due to heavier formula weight of Na vs Li; 160 Wh/kg vs 200-250 Wh/kg  (+) Better low temperature performance  Most likely to be used in places where lots of batteries are needed and weight/space is less impt, i.e. grid storage or heavy vehicles. | |

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| Key Terms | | | "minerals" = crystalline inorganic compounds (often complicated in formula) found in nature  Some minerals can be mined and undergo treatment to obtain a particular "element" or elements, i.e. malachite Cu2CO3(OH)2 is to get Cu  So when it is mentioned that an EV uses more “minerals” than an ICE vehicle actually means EVs uses more "elements”  Other publications use “Metals” since most of the elements concerned are metals, but since graphite (a non-metal) is involved, “Materials” can be used as a more general term | | | |
| Process | | | E.g. Cu, Ni, Co, Mn Ore mined from the ground (Ore = concentrations of minerals in rock that are high enough to be economically extracted for use) -- Refining --> Raw materials, i.e. Li2CO3, NiSO4 -> Electrode material production, e.g. Copper metal -> Cell production -> Module and pack assembly -> EV production  To control costs and guarantee access to battery metals, EV makers now want to be vertically integrated and own their own mines | | | |
| Moves by EV companies | | | Elon Musk 2022: It’s not we wish to buy mining companies, but if that’s the only to accelerate the transition, then we will do that  Elon Musk 2023: The “limiting factor” is refining lithium, not actually finding it, as no country has a monopoly on deposits  To secure raw materials for their EVs battery packs, auto companies are increasingly dealing directly with mining companies:  • Ford has signed deals with BHP, for nickel and Rio Tinto, for lithium • China BYD wins Chile Lithium Extraction contract... | | | |
| BYD (Build Your Dreams) | | | A startup EV company which started off (and still is) as a battery manufacturer. Largest EV (BEV+ PHEV) in the world in 2022  Pivoted into auto business in 2003, world's first PHEV. **Diversified** in product offerings: electric buses, solar PV & storage, battery  manufacturing, monorails, handset component and assembly, masks  **Vertically integrated** for EV business: lithium and nickel mines; EV semiconductor chips; cell, battery pack manufacturing  Well known inside China but now starting to export EVs aggressively overseas. Founder and current CEO has chemistry background | | | |
| Materials for EV  (EV uses more than ICE) | | For (+) electrode: Li, Cobalt, Nickel, Manganese, Iron (depends on chemistry used. Fe & Mn are relatively abundant, and won't be discussed)  For (-) electrode: Graphite. For electric motors: Rare Earth Metals.  Copper (Cu) also used in electrical wires as it is a good conductor of electricity.  For EVs, large amounts of Cu is needed for motor coil in electric motors and charging stations  EV compared to an ICE vehicle needs ~ 4x more copper | | | | |
| Demand for materials | | | Demand for Li, Graphite, Co, Ni and rare earths will greatly increase in the green economy  Need increased mining to satisfy the demand either by opening new mines, increasing production in existing mines or re-opening closed mines. Price of these materials is likely to rise as demand rises  Recycling will becoming ever more important | | | |
| Mineral Extraction | | - Geographical concentration- key minerals are more concentrated in fewer countries than oil and gas, i.e. Democratic Republic of Congo for Cobalt (70%). Processing of many materials in China. Potential geopolitical risk.  - Long project lead times- typically 10-15 years from discovery to first production.  - Declining resource quality - high quality (concentration), easily accessible deposits are typically exploited first. More energy is needed and more waste/pollution will be generated exploiting lower quality ores.  - Water- lots of water is needed to mine metals such as Cu and Li. Over 50% of Li and Cu production is in areas with high water stress levels.  - Environmental and social considerations- the need to avoid harming the environment and local communities at all stages of extraction.  All these will lead to:  1. Mineral-producing countries will gain geopolitical power  2. Regions with large unexploited mineral reserves will gain strategic importance  3. International r/s shift towards countries possessing renewable energy tech and technical know-how on minerals for renewable energy. | | | | |
| Inflation Reduction Act (US) | | | Aug 16, 2022. $369 billion allocated to climate change & energy security & boost US capacity to produce wind turbines, solar panels & EVs  Existing EV subsidy of up to $7,500 will be extended but (i) final assembly of EV must be in North America, (ii) 50% of battery components must be manufactured or assembled there, and (iii) sourcing of the mineral content of the battery  At least 40% of the critical metals in the battery - Li, Ni, Co, Mn - must be extracted, processed or recycled from the US or a Free Trade Agreement (FTA) partner. That percentage rises to 80% in 2026  "Reshoring" = Metals coming from US. "Friendshoring" = Metals coming from FTA partners.  This is in contrast to previous “offshoring” efforts by businesses to maximize profits without geopolitical considerations. | | | |
| Mining Industry | | | High capital expenditures (CAPEX), especially for deep deposits. Economies of scale – very large machines and vehicles  Large scale mining controlled by few companies, i.e. Glencore, BHP, Rio Tinto  Nationalization of resources – control of mineral industry by the government, i.e. Mexico, Chile for lithium | | | |
| Stages of Mining | 1. Exploration: Locating & performing geological studies of ores. Ensuring ores are of sufficient quantity and grade  2. Pre-Feasibility and Feasibility studies: mining and processing methods are examined, and economic viability assessed with consideration of social and environmental impacts. Financing is obtained.  3. Permitting: relevant environmental permits and mining licenses are obtained.  4. Development: construction of access roads, preparation and clearing of site  5. Mining: extraction of ores. Some mines can remain open for many decades  6. Processing: the ore undergoes preliminary processing to increase metal concentration  7. Reclamation and Closure: Close mine when not profitable. Reclamation aims to restore area before to pre-mining condition before closure. | | | | | |
| Types of Mining | | | 1) Open pit - Minerals are located close to surface. Cheaper to mine but extensive restoration needed after mining completed, eyesore  2) Underground - Minerals found deeper. Expensive and capital intensive. Safety issue due to potential collapse of mine shafts | | | |
| Operations from ore to pure metal | | | |  |  |  |  | | --- | --- | --- | --- | | Steps | Description | Primary Solid Waste | Typical metal purity | | 1) Mining | Removal of overburden to reach ores | Overburden | 0.25 - 1% | | 2) Processing | Onsite separation and concentration of ores to produce metal concentrates | Tailings | < 20% | | 3) Purification | Further processing/purification offsite via smelting and refining to produce high purity products | Slag | > 99% | | | | |
| Mineral processing | | | After mining, ore will be processed to concentrate the metal of interest. Essentially, ores are crushed into fine powder, then sieved.  Ore-rich powder are then separated using chemical/physical mtds depending on metal. E.g. ore powders can be (i) floated on water (froth floatation) w aid of air bubbles and chemicals or (ii) magnetic separation using magnets  Tailings are mostly dumped into ponds created from naturally existing valleys, and secured by dams to form tailing ponds  Stability of a tailings dam must be constantly monitored for potential dam collapse | | | |
| Smelting | | | After ore is concentrated, it goes to a smelter which is typically located away from the mine due to scale of operations  For transition metals like Ni, Co, Cu, the ore is not a pure metal, it is found as a compound (mineral), i.e. Nickel exist in nature as oxide (mineral laterite), sulphide (mineral pentlandite), [(Fe, Ni)9S8]  Smelting is needed to obtain the elemental metal from the concentrated ore, i.e. [(Fe, Ni)9S8] -> -> Ni + SO2 (sulphur dioxide)  Just need to know heat is applied, often w a reducing agent. Slag = waste left behind by smelting  This is followed by refining, e.g. electrolysis to improve purity. | | | |
| Case study 1: Grasberg Mine in Papua, Indonesia (since 1973) | | | Grasberg Mine: world's largest gold and 2nd-largest Cu mine, is located in the highlands near Puncak Jaya, the highest mountain in Papua.  Operated by PT Freeport Indonesia (PT-FI). Freeport-Mcmoran (US company) used to own 90% until 2017 w Indonesian govt owning 51%  4.1 km above sea level. A 116 km road and pipeline, port, airstrip, power plant and a new town was built  Extremely large open pit mine (2 km in diameter) that can be seen from space  2016 production: 482 million kg of Cu, 33 million kg of Au. Tailings generated at 700,000 tonnes/day  Controversy: environmental issues, profit sharing for locals. | | | |
| Case study 2: Lithium | | Top producers: South America, Australia. Exist in native form as spodumene, LiAl(SiO3)2 as ores which need to be mined  Lithium brine (salt solution) also another source of lithium. Can be pumped from underground and left to concentrate by evaporation (~ a year), more economical than mining  “Li Triangle” — region of Andes mountains that includes parts of Argentina, Chile & Bolivia containing most of world’s known reserve of Li  Membranes for lithium extraction are in the research stage as evaporation is an irreversible loss of water. | | | | |
| Resource and Reserves | | A Mineral *Resource* = concentration or occurrence of solid material of economic interest in or on the Earth’s crust in such form, grade or quality and quantity that there are reasonable prospects for eventual economic extraction. *Reserves* *Resources*  *Reserves* = amt of a resource than can be economically extractable at current prices and given current tech and regulatory requirements.  • *Proven reserves* (P90): 90% or higher prob of extraction • *Probable reserves* (P50): > 50 - < 90% prob of extraction  Reported Reserves of a country changes all the time w extraction rates, new discoveries, price & improvement of extraction/processing tech | | | | |
| Case study 3: Cobalt | | | Cobalt containing battery chemistries, i.e. NMC account for 74% of EV mrkt. Top Producers: Democratic Republic of Congo (74%), Australia  In 2021, for first time, EVs becomes the largest end use sector of cobalt (34%), anticipated to be 50% by 2026.  Exist in native form as carrolite (Cu-Co-sulphides), laterite (Ni-Co-oxides)  Artisanal & small-scale mining (ASM) accounted for 12% (14.5 kt) of DRC mined supply in 2021 ASM is often associated with human rights issues, i.e. child labour. | | | |
| Case study 4: Rare earth metals (14 elements) | | | Rare Earth Metals or Rare Earths (REs) are not that rare, they fall into the 50th percentile of elemental abundances  REs with their f-electrons (14 electrons maximum) are key in making powerful permanent magnets such as Nd-Fe-B intermetallics (compounds of metals) used in EV motors  Rare earths are more expensive to mine and process than most metals when not mined with environmentally harmful chemicals. REs are very similar in chemistry thus hard to separate  To produce 1 ton of RE metals, 75 tons of aqueous acid waste and 1 ton of radioactive residue are created  China has largest market share with RE extraction (60%) and processing (90%).  In 2010, the share of China for RE extraction was >90% but in 2020 it has dropped to ~60% as other countries develop alternative sources. | | | |
| Environmental impacts of mining | | | | | 1) Air: Dust from mining activities (excavation, blasting, crushing of ores). SO2 released from smelting leads to acid rain  2) Water: Acidic mine drainage (AMD) - mined materials (w large amt of sulphides) interact w O2 & H2O to form sulphuric acid (H2SO4)  Acid will dissolve other minerals to release metal ions and/or run into streams and decrease pH which affect wildlife  Metal ions are problametic as they are persistent in the environment  3) Soil pollution: pollution of soild by metal ions. 4) CO2 emissions: e.g. 5-15 tons of CO2 released per ton of lithium mined | |
| How to mitigate environmental impact | | | | | Before approving mining, environmental impacts is considered at all stages of mining activity: Environmental Impact Assessment (EIA)  Mine reclamation & closure plans must detail how company will restore site to condition that most resembles pre-mining quality  Prevention of release of toxic contaminants from various mine facilities in perpetuity must also be detailed  Source of financing at all steps must be clear  Govt must have resources and authority to administer, monitor and enforce laws and policies on mining | |
| Social impacts of mining | | | Create wealth, bring jobs, roads, schools, but benefits and costs may not be shared equitably, especially with the local population  Local population may be relocated. For indigenous people, these areas may be ancestral lands  Health and traditional livelihood of local population may be affected by polluted air, water and soil from mining  Miners and workers arriving may create social tensions btw locals and newcomers due to competition for land and public services  Miners and workers arriving are predominantly male may result in increase in social ills such as gambling and alcoholism | | | |
| Natural Resource Curse | | | “The curse of natural resources” is used to describe the apparent paradoxical observation that countries with great natural resource wealth tend perform badly (e.g., grow more slowly) than resource-poor countries. | | | |
| Causal observation 1: No overlap btw set of countries with high natural resources and set of countries that have high level of income.  Causal observation 2: Extreme resource-rich countries such as Oil States in the Gulf, Nigeria, Mexico or Venezuela have not experienced sustained rapid growth.  3: Controlling for previous growth rates (for omitted variables) by Sachs and Warner (1997) and direct control of geography and climate variables by Sachs and Warner (2001) do not eliminate the negative r/s btw natural resource abundance and economic growth. | | | |
| 1. Natural Resources crowds-out activity  2. Activity drives growth.  3. Therefore Natural Resources harm growth.  has been identified as traded- manufacturing activities by Sachs and Warner (1995, 1999) and Sachs (1996).  Traded-manufacturing activities generate +ve externalities | | | E.g. Positive shock from the natural resource sector  excess demand for non-traded products  higher non-traded prices, including non-traded input costs and wages  squeezes profits in traded activities e.g. manufacturing that use those non-traded products as inputs yet sell their products on international markets at relatively fixed international prices  decline in manufacturing  slower growth |
| Resource abundant countries tended to miss-out on export-led growth  Evidence in support of curse is weak at best. Reasons include: measurement issues (how to measure resource abundance) & hetrogeneity in effects (many diff channels through which resource abundance can shape growth) | | | |
| Many diff channels through which resource abundance can shape growth  1. Volatile or declining price of natural resources compared to manufactured goods  2. Lack of positive spillovers, e.g. in human capital accumulation & technology from natural resource sector  3. Dutch disease (natural resource gaining a share of labour at the expense of manufacturing and other export driving sectors)  4. Interaction of natural resource wealth and institutions of governance – e.g. natural resource wealth institution weakness or embezzlement lower productivity or voracity effect (redistribution of export windfall) persistent low growth | | | |
| An alternative view: Countries that can handle the resource curse well tend to have better governance and property rights. | | | |
| Case study: Latin America | | | A commodities superpower for this century or a potential victim of natural resource curse. SWOT analysis  Strengths = Dominant player in copper. Weakness = Political instability  Oppportunities: Global transition to clean energy demand for its resources. Threats: Climate change (floods affect mining operation) | | | |
| Emerging Frontier: Deep seabed for EV metals | | | | Rich mineral resources lie in international waters of > 200 m deep that cover nearly two-thirds of earth -> property rights are ill-defined  International Seabed Authority (ISA), UN–appointed body to manage the riches of deep seabed for the “common heritage of mankind”  With increasing demands and better tech, the race to mine the deep seabed has begun with exploratory efforts at present.  Marine biologists are apprehensive on possible profound and widespread effects of deep seabed mining on deep sea marine life | | |
| Recent developments on deep sea mining | | | | In 2021, the pacific island of Nauru declared its plan to start seabed mining  ISA council then has 1 years to finalize rules that would cover all aspects of seabed mining, from environmental regulations, to sharing of proceeds (theoretically proceeds should be shared, not just the country funding exploration)  After three weeks of discussion, no conclusion on Aug 2022.  Currently unclear whether exploration will begin in a year’s time with the absence of agreement  In July 2023 ISA said it will not issue any extraction permits for deep-sea mining regulations, and it indicated they completed until 2025. | | |
| SG and deep sea mining | | | | Only Ocean Mineral Singapore has been granted a license to conduct exploration studies for deep sea mining of metals.  It has signed an exploration contract w the ISA w SG as the sponsoring state | | |
| Use of more abundant materials | | | Instead, scarce/expensive materials can be substituted with abundant/cheaper alternatives  R&D is needed for successful substitution to occur. It is harder than it sounds: existing elements are used for a reason!  Some examples of substitution: 1) Use of NMC electrode instead of pure LiCoO2 (LCO) 2) Use of LiFePO4 (LPO) instead of LCO  3) CATL has commercialized Na ion batteries. Na is much more abundant than Li. EVs with Na batteries are being deployed.  4) EV motors that do not use rare earths can be employed, i.e. induction motors instead of permanent magnet motors.  Tesla in 2023 stated their next generation of vehicles will use motors with no rare earths. | | | |

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| Gigafactory (Giga = 1 billion, 109) | Term first publicly used by Elon in 2013. To meet Tesla’s projected production of EVs in 2013, need existing entire worldwide supply of LIBs  First Gigafactory in Sparks, Nevada, USA in 2016 with Panasonic making the LIBs.  Tesla now has four Gigafactories worldwide producing LIBs for EVs and energy storage.  A Gigafactory produces ≥ 1 GWh of batteries yearly. In mid 2018, Giga Nevada produced 20 GWh on an annualized basis.  From Benchmark’s CEO: world needs 20 TWh (1 Tera = 1012) of annual battery production for a renewable future. | |
| Cost savings | 1. Economies of scale: cost per unit good by volume of goods produced. Can be due to in fixed costs per unit of output, better bargaining power for raw materials, etc  2. Innovative manufacturing: e.g. Tesla is using a dry process to coat electrodes instead of solvent-based techniques  3. Reduction of waste (scrap): reduction of waste per unit output as better technology can be employed  4. Locating most manufacturing processes under one roof = savings in transport costs, efficiency of production | |
| Top EV battery manufact-urers in 2022 | |  |  |  | | --- | --- | --- | | CATL | 34% | China | | LG Energy Solutions | 14% | South Korea | | BYD | 12% | China | | Panasonic | 10% | Japan | | SK ON | 7% | South Korea | | |
| Decrease in cost of LIBs | in gravimetric energy of LIBs have been occuring at the same time with in cost of LIBs  Since its invention in 1991, price of Lithium-ion cells have by 97%  Wright’s Law : For each doubling of production, the associated cost by a certain %. First observed by Wright for aircraft production  For LIB production, prices an average of ~19% (19% aka learning rate) for every doubling in cumulative (total) capacity.  When demand for product , meeting demand = more opp to learn and implement these learnings in production which further costs.  When battery pack prices to <US $100/kWh, automakers should be able to produce and sell, without subsidies, mass-market EVs at the same price (and with the same margin) as comparable ICE vehicles in some markets. | |
| Increase in costs of raw materials | share of cathode (positive electrode) material cost to EV battery pack cost. Positive electrode cost > Negative electrode cost generally  Price of EV metals, especially Li and Ni are above historic averages  Recently, material costs for LIB positive electrode (cathode), especially for those with Co and Ni chemistries has  Nickel, cobalt and lithium prices respectively by 36%, 125% and 750%, between January 2021 to January 2022  Recent conflict in Ukraine has further price of Ni since Russia is the 3rd largest supplier of Ni worldwide  Paper indicates growing importance of LFP chemistries.  To gain market share, companies have to lower their sales prices of EVs, even though material cost is increasing | |
| Reducing costs of LIBs in the long run | | 1) quality control (QC) to minimize scrap rate in cell manufacturing  2) novel electrode processing and engineering to processing cost and energy density and throughputs  3) material development and optimization for lithium-ion batteries with high- energy density. |
| Recycling LIBs | Increasing supply of EV batteries for recycling. Creates circular economy. Lessen need for additional mining  A "spent" EV LIB at the end of its useful life is still usable as it has still some capacity and can be re-used for other purpose  E.g. power grid storage - store electricity from intermittent sources like wind and solar farms  Although repurposing LIBs does not solve the end-of-life problem, it will reduce immediate waste.  Ultimately the LIB will need to be either disposed or recycled.  Barriers to recycling: costs, lack of regulations, lack of standardization of battery design | |
| Issue of LIBs disposal | LIBs consists of many chemicals and if not disposed properly, there will be pollution (especially transition metal ions) or fire issues  Extended Producer Responsibility: an environmental protection strategy to reach an environmental objective of a decreased total environmental impact of a product, by making the manufacturer of the product responsible for the entire life-cycle of the product and especially for the take-back, recycling and final disposals. "If you make it, you need to take it back" | |
| Role of govt legislature | EU proposed legislation on battery waste (2020) (i) extended-producer responsibility targets for collection and recycling  (ii) specific recycling rates for Li, Co and Ni (iii) specifying targets for the use of recycled materials in new batteries to incentivize demand. | |
| Mtds to recycle LIBs | After collection, battery packs will be tested, discharged and disassembled  1) Hydrometallurgical: using acids such as aqueous hydrochloric acid (HCl) or bacteria to leach metal ions, followed by separation, extraction and precipitation to obtain metal salts. Low temp process with tailorable chemistries.  2) Pyrometallurgical: using high temps (>700) to melt and reduce battery materials to obtain metals. Most mature technique, highly effective at recovering Ni, Co, Cu.  3) Direct physical recycling: removal & refurbishing battery materials from cells w/o changing their chemical form. Still in research phase. | |
| Companies doing LIBs recycling | Green Li-ion: 1) Capable of recycling 14 tonnes of LIBs a day  2) Recover more than 90% of precious metals from LIBs for reuse in battery production  3) Recycled materials can be used for production of new batteries | |
| Redwood materials: - Startup founded by Jeff Straubel, former co-founder and CTO of Tesla till 2019. Now a board member of Tesla.  - Signed partnership with Ford in Sep 2021. Redwood will get used battery packs from Ford and in turn Ford will get recycled minerals to make new packs. Other customers include Tesla, Amazon. | |

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| EV Marketing Trends | Increasing expenditure on EV marketing compared to ICE. Less ads for ICE vehicles  China has highest num of EV sales, while Norway has highest EV share for new cars.  Top selling model in US changed from small cars to luxury cars to family sedans and hatchback SUVs  BEV sales in SE Asia grew by 894% in Q2 2023  Big decline in prices as OEMs like Vinfast and BYD introduced cars w better sticker appeal for borader range of customers | |
| Consumers' constraints and behaviour | Economists model as constrained optimization problem: consumer want to maximize lifetime utility (happiness/satisfaction) subject to lifetime budget constraint. This uses 2 building blocks: 1) preference & 2) budget constraint  What is observed in the market is the price and quantity traded at equilibrium.  1) Preference not directly observable (latent), so economists conduct experiments/surveys to elicit one's preference  - E.g. if there are only apples & oranges in mrkt and only 1 period. Preference: Utility = f(num of apples, num of oranges)  - E,g, if there is only apples in mrkt and 2 periods.  Utility = f(num of apples today, num of apples tmr). E.g. Utility = num of apples today + \* num of apples tmr  - Eliciting subjective discount rate, . Multiple price list design (give diff prices, let consumer choose)  - Subjective discount rate & delayed gratification ??? Marshmallow Test  2) By looking at factors such as consumer’s labour-leisure preference, endowments (e.g., bequests and health), education level, wage rates in the economy through the supply and demand for workers in each sector. | |
| Consumers' stated preference through survey | |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | Preferred engine type 2020 | Thailand | SG | Malaysia | Indonesia | Philippines | Vietnam | | BEV | 14% | 9% | 4% | 4% | 3% | 3% | | Hybrid | 29% | 35% | 29% | 20% | 16% | 16% | | Others | 57% | 56% | 68% | 77% | 81% | 81% | | Willingness to pay for EV 2020 compared to average car | | | | | | | | Same | 55% | 65% | 47% | 61% | 48% | 47% | | Less | 39% | 21% | 43% | 23% | 39% | 38% | | More | 4% | 13% | 10% | 13% | 12% | 9% | | Premium | 1% | 2% | 0.4% | 3% | 1% | 6% | | Leading concerns of consumers | | | | | | | | Lack of charging structure | 19 | 34 | 35 | 39 | 31 | 38 | | Safety concerns | 19 | 18 | 18 | 12 | 24 | 22 | | Cost | 18 | 20 | 21 | 10 | 13 | 12 | | Time to charge | 16 | 14 | 11 | 15 | 12 | 19 | | Driving Range | 24 | 10 | 12 | 22 | 17 | 7 | | Lack of choice | 4 | 4 | 3 | 1 | 3 | 3 |   Other surveys for Asia, Global in lect notes Chapter 6 | |
| Consumers' Preference through Discrete choice experiments | For each attribute, have diff levels. E.g. Purchase price: 25% (base), 50%, 75%  Let consumers choose btw 2 sample choices. A: purchase price = 50%, range = 90km, .... B: purchase price = 25%, range = 60km...  Using mixed logit model, Bera and Maitra (2021) estimate commuters' willingness to pay (WTP) for a set of key PHEV-specific attributes.  UPHEV­ = -0.0037 \* Purchase Price + 0.0156 \* Fuel cost reduction + 0.0124 \* Electric range + 0.0058 & Public charging station  - 0.1796 \* Battery recharge time + 0.1154 \* Battery warranty - 0.0193 & Tailpipe emission  Key factors identified in literature. Consumers' buying decisions for EV depends on:  1. Vehicle attributes: price, fuel cost, range, recharge time, acceleration time, battery warranty, tailpipe emission  2. Service attributes: availability of home-based charging, availability of public charging, service speed of public charging  3. Sociodemographic attrs: age (young likely to buy), education, income, urban dwellers (lower mileage needs), concerns abt environment | |
| Theory of diffusion of Innovation & Mrkt segmentation | | Mrkt segmentation = diff characteristics of groups that adopt new innovations at diff times  Roger's Diffusion of Innovation = seq of adopter stages and % of population.  First Movers: 2.5%. Early adopters: 13.5%. Early majority: 34%. Late majority: 34%. Laggards: 16%  Mrkt segmentation: Key behavioural differences. Brand loyalty, research, ownership benefits, price sensitivity  Other findings in lect notes 6 |
| Role of govt | Nordhaus: Double externality for low-carbon innovations. Public returns on innovation many times larger than private returns  1) Normal innovation externality (external benefits for new tech). 2) Climate impacts externality  Fixed climate externality through carbon pricing and Pigouvian taxes  Incentivize investment in low-C tech and eco-system infrastructure (charging stations and standards) | |
| Addressing price | Purchase cost of EV > ICE (in US abt $15,000). Expected total cost of ownership EV < ICE  Lifetime fuel and maintenance cost EV < ICE (only 1/3 of potential savings perceived by consumers)  Direct point of sale grant, e.g., US from $2.5K to $7.5K federal tax incentive if assembled in the US.  Disincentives for ICE, e.g. Norway EV buyers exempt from VAT, heavier gasoline vehicles – additional tax  Distributional consideration – cap incentives at certain price point, e.g. in Germany, cars selling at more than 50K euros are not eligible. | |
| Addressing non-price concerns | Special road access to high occupancy vehicle lanes or bus lanes (during the early phase of adoption) e.g., China and Norway  Free parking for EV. Exemption from toll or congestion fees  Considerations: - Equity as early EV adopters are from the high income segment  - Transparency required about the duration of these incentives as they are not meant to be permanent. | |
| Charging infrastructure – chicken and egg dilemma. Charging infrastructure and standards have network effects, hence returns to scale.  When a network effect exists, the value of a good or service depends on the numbers of others using it – externalities.  E.g. Owning a phone is more valuable as the number of customers on the telephone network grows. Technically, network effects refers to the effect that one individual user of a product or service has on the value of that product or service to other people.  Public charging infra on-street and at work – public good, especially in high density urban areas with limited home charging.  Govt to subsidies investments or grant concessions to companies developing the charging infrastructure. Future cost for charging will decrease with increase in scale.  Improve economies of scale by standardising the charging ecosystem – multihoming.  Multihoming - condition where users can be associated with more than one platform in markets with more than one platform. | |
| Charging of EVs | A diagram of a power supply system  Description automatically generatedCharging = moving electrons from mains to EV battery pack  1) Most common: Conductive charging via cables  2) Research: Inductive charging via pads  3) Out of the box: Batterp swap of used for fully charged pack  Battery is charged using DC. But electricity from mains is AC  Thats why need AC/DC converter in the onboard charger (green rectangle)  Conductive charging has diff speeds, w level 1 slowest and level 3 (supercharger). Level 1 and 2 can be installed in residences  Level 1 (AC 120V): 1.4 or 1.9kW, 12-16A  Level 2 (AC 208-240V): ≈ 7kW, 30A  Level 3 (DC 400-900V): ≈ 50kW, 60A | |
| Conductive charging | A diagram of a car  Description automatically generatedSG uses Type 2 and CCS2  Tesla First supercharger built in 2012, same time as Model S. Now 50,000+ worldwide (2023)  Uses proprietary standard but recently opened (Nov 2022) as NACS (North American Charging Standard)  Current version is V4 (2023)  V1 (90 kW), V2 (150 kW), V3 (250 kW), V4 (1 MW)  V3 and V4 has liquid cooling in cables to handle the higher currents  For North America in Feb 2023, chargers with Magic Dock (inbuilt detachable CCS adaptor) to charge non-Tesla vehicle. | |
| Inductive charging | Diagram of a car charging station  Description automatically generatedAKA contactless charging  Uses Faraday’s law of electromagnetic induction : The induction of an electromotive force (i.e. voltage) by the motion of a conductor across a magnetic field or by a change in magnetic flux in a magnetic field. E.g. if a conductor is set in an oscillating magnetic field, an emf is detected  (+) Convenient, no exposed parts, potential for dynamic inductive charging on the move (while driving)  (-) Cost, alignment issues and lower efficiency than conductive charging. | |
| Battery Swap | Swapping a used battery pack for charged battery pack for EV was already in existence at the turn of the 20th century  For a modern EV whose battery pack is at the base of the vehicle and not easily accessible presents a practical engineering challenge  Robotics is one solution and greatly speeds up the process  For EVs, Elon Musk demonstrated this idea in 2014 for Model S and X, however this idea did not take off for Tesla, instead they rely on their superchargers. “battery swapping is riddled with problems and not suitable for widescale use”  The Shanghai-based car company NIO is well known for their proprietary battery swapping stations  May 13, 2023: **1,383** battery swapping stations, mostly in China. **20 million battery swaps** achieved. One battery swap every 1.6 seconds.  Collaborating with traditional fossil fuel companies like Shell and Sinopec to offer battery swapping in their petrol stations and jointly construct charging stations with battery swap stations  The automated swapping station allows battery pack to be swapped in <**5 min**. NIO EVs use standardized 70 and 100 kWh packs.  BaaS (Battery as a Service): NIO EVs are sold without battery packs and users pay a monthly lease. Thus the purchase price of its EV is cheaper as a result compared to other EVs. Lease costs must be considered for total cost of ownership. | |
| SG | 1) Set goals: - Enhanced 2030, National Determined Contribution (NDC): peak emission at 65 MtCO2e, 36% in emission intensity from 2005 levels by 2030.  - Long-term Low-Emission Development Strategy (LEDs): 33 MtCO2e by 2050. Net Zero emission in the second half of the century  - Transport sector: – Zero private vehicle growth – 9 in 10 peak period journey on “Walk, Cycle, Ride” by 2040 – Cleaner vehicles by 2040  2) Pigouvian taxes and mrkt-based mechanism: - carbon tax w initial rate of $5/tCO2e -> $10-15/tCO2e by 2030  - EV Early Adoption Incentive (EEAI), Enhanced Vehicular Emissions Scheme (VES), Commercial Vehicles Emissions Scheme (CVES), Enhanced Early Turnover Scheme (ETS)  3) Invest in and Adopt Efficient Tech: - Carbon capture, utilization and storage, low-carbon fuel & regional power grid  - More charging stations - Electric Autonomous Vehicles. Why autonomous vehicles:  1. Match flexible routes and schedules. 2. Overcome manpower constraints. 3. Narrow gap btw private and public transportation | |
|  | For electric autonomous vehicles, consumers prefer a subscription service that focuses on convenience, flexibility & availability of vehicles  More statistics on EV ecosystem in lect notes 6 | |

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| EV industry developments | | | 2023, largest OEMs by volume - Tesla and BYD are increasing mrkt share. BYD, Tesla, Volkswagen, SAIC, Geely  Toyota to produce solid-state batteries. Kia new EV include cars that can turn into bedrooms. Stellantis investing more in Cu mining  Manhattan EV charging sites outnumber gas stations 10 to 1  Beyond passenger cars: Tesla Semi Truck  - 0 emission Semi. - Range of 500miles/805km. - Expected eligibility for federal tax credits ($40,000 per heavy-duty truck).  - Corporate clients include Pepsi & Walmart. - Other competitors for battery electric big-rigs (Nikola Corp and Volvo AB) | |
| Producer's problem | | Allocate scarce resources (factors of production such as labour and capital) 1. across products 2. across time 3. choosing qty to produce  Constrained optimization problem: producer want to max profit by allocating factors of production Given state of production tech and mrkt structure. Building blocks include profit fn (price\*qty - wages \* labour - rental cost)and production fn | | |
| Competition and Mrkt Structure | | Factors to consider on how much to produce, price to charge, num of ppl to hire depends on cost and competition  1) Monopoly: 1 seller. Barriers to entry. 2) Oligopoly: Few sellers. Standardized or differentiated products. Interdependent. Barriers to entry. 3) Monopolistic Competition: Many firms. Differentiated (similar but not identical) products. Free entry & exit.  4) Perfect competition: Many buyers & sellers. Standardized products. Free entry & exit. Well-informed buyers & sellers  1) -> 2) -> 3) -> 4) . 1), 2), 3) are imperfect competition | | |
| Mrkt structure describes the characteristics of a mrkt that influence the buyers and sellers when they come tgt to trade  By classifying competition and understanding their characteristics, can make predictions abt: - price and output decisions of a firm, - short-run profits, - long run profits, - impact of changes in consumers' taste, income, tech, policies and regulations, - relate mrkt structure to economic efficiency | | |
| Perfect Competition (PC) | | 1. Large num of buyers and sellers: No individual decision maker can significantly affect price of product by changing qty it buys or sells  2. Standardized/homogeneous products offered by sellers: Buyers don't perceive diff btw products of 1 sellers and another  A diagram of a market  Description automatically generatedDue to 1 & 2, each buyer and sellers is a "price taker" – takes the price as given (beyond his control)  - Cannot incr price w/o losing all its customers. - Demand curve faced by a PC firm, d is a straight line. - Marginal revenue (MR) from additional unit = price  3. Easy entry into and exit from mrkt: - No sig barriers or special costs to discourage new entrants  - Everyone have access to same tech & inputs. - No barriers to exit  4) Well-informed buyers and sellers, thus single mrkt price: - Buyers and sellers have all info relevant to their decision to buy or sell | | |
| Is PC realistic? | | | Yes for some mrkts. E.g. commodities such as wheat  No, for other mrkts where 1 or more of the assumptions/characteristics do not hold  Model of perfect competition is powerful as it: - can approximate many mrkts. - Serves as benchmark for analysis of economic efficiency | |
| Monopoly | | A graph with a red line  Description automatically generatedMrkt in which only one firm sells a product with no close substitutes: A monopolist face the mrkt demand curve.  “No close substitutes”: To decide whether a mrkt or firm is a monopoly, depends on how easy for consumers to switch to other sellers  A monopoly firm has mrkt power = *ability to influence the mrkt price* of the product it sells.  (e.g. SP Group in SG for electricity) | | |
| Monopolies exist because:  1. Economics of scale (EOS): more output firm product, lower its cost per unit  Natural monopoly arise due to EOS. Single firm can produce for entire mrkt at lower cost than could 2 or more firms (e.g. SP Group)  - Long run average total cost (LRATC) slopes downwards due to huge fixed cost and small marginal cost  2. Legal barriers: a) Protection of itellectual property: - Enjoy monopoly but encourage R&D. - Restrict competition but encourage R&D  - E.g Patents: temp grant of monopoly rights over a new product/invention, typically for 20 years  - E.g. Copyright: grant of exclusive rights to sell a literary/musical/artistic work, lasting at least 70 years  b) Govt franchise: Govt-granted right to be sole seller of a product or service (e.g. US Postal Service).  A diagram of a market  Description automatically generated- When govt thinks mrkt is a natural monopoly, to further public interest by ensuring that there are no competitors that will reduce market share and cause cost per unit to rise  - Seller must submit to either govt ownership and control or govt regulation over its prices and profits  - Eg. Electricity prices in Singapore is regulated by the Energy Market Authority to reflect actual cost of electricity  3. Network externalities  - Additional benefits enjoyed by all users of a good or service because others use it as well  - Joining a large network is more beneficial than joining a small network  - E.g. mrkt for computer operating systems • Social networking sites | | |
| Monopolistic competition | | | | 1. Many sellers. 2. Differentiated products (quality, features, locations, subjective - role for advertising and branding). 3. Free entry & exit  E.g. Books, clothing, fast-food and restaurants, Bars  Due to 1 & 2: monopolistically competitive firm faces a downward sloping demand curve (same as electricity above, but curve is flatter)  - To sell more Q, firm must lower P. Revenue from selling 1 more unit is less than current price, MR < P  - Can incr price w/o losing all its customers, unlike in Perfect Competition. - Not price takers |
| Num of firms in mrkt may not be optimal due to external effects from the entry of new firms.  Product-variety externality: surplus that consumers get from the introduction of new products.  Business-stealing externality: the losses incurred by existing firms when new firms enter the market.  Inefficiencies of monopolistic competition are subtle and hard to measure. No easy way for policymakers to improve the mrkt outcome.  Differentiated products are everywhere. The theory of monopolistic competition describes many markets in the economy. |
| Summary | | |  |  |  |  | | --- | --- | --- | --- | |  | Monopoly | Monopolistic Competition | Perfect Competition | | Num of sellers | 1 | Many | | | Free entry/exit? | No | Yes | | | Long run economic profits | Positive | 0 | | | Close substitutes | None | Many (differentiated products) | Many (identical products) | | Mrkt power | Yes | | No | | Demand curve facing firm | Downward sloping (Mrkt demand) | Downward sloping (More elastic than monopoly) | Horizontal | | Objective of firm | Profit maximization | | | | Profit maximising rule | MR = MC (Marginal revenue = Marginal cost) | | | | Profits in short run | Positive, 0 or Negative | | | | Price taker | No (downward sloping demand curve) | | Yes (flat demand curve) | | Price (mark-up?) | P > MC | | P = MC | | Output at efficient scale | No | | Yes | | | |
| Oliogopoly | | 1. only a few sellers offer similar or identical products.  2. A firm’s decisions about price or the quantity to produce can affect other firms and cause them to react.  3. The firm will consider these reactions when making decisions.  4. Game theory: the study of how people behave in strategic situations is used to analyse oligopolistic markets. | | |
| Strategic behaviour for Oligopolists & Nash Equilibrium  - Collusion: an agreement among firms in a mrkt about quantities to produce or prices to charge.  - Cartel: a group of firms acting in unison.  - Oligopolists are better off cooperating to reach the monopoly outcome.  - However, due to self interest, each firm has an incentive to cheat (deviate from the cartel’s agreement to steal market share)  **- Nash equilibrium**: players interacting w one another each chooses his best strategy given the strategies that all the others have chosen. | | |
| - Game theory helps us understand oligopoly and other situations where players interact and behave strategically.  - Dominant strategy: a strategy that is best for a player in a game regardless of the strategies chosen by the other players. | | |
| Prisoners’ dilemma: a game between two captured criminals that illustrates why cooperation is diff even if mutually beneficial.  - Because each pursues his or her own interests, together they reach an outcome that is worse for each of them  Dominant strategy: Action A. Nash equilibrium: Both take action A   |  |  |  |  | | --- | --- | --- | --- | |  |  | Player 2 | | |  |  | Action A | Action B | | Player 1 | Action A | Bad, Bad | Best, Worst | | Action B | Worst, Best | Good, Good |   E.g. Ad wards: 2 firms spend millions on TV ads. Each firm's ad cancels out effects of other, both firms profits fall  E.g. OPEC (Organization of Petroleum Exporting Countries): Tried to act like cartel, agree to limit oil production. Some countries renege  E.g. Arms race: Better if countries disarm. Each has dominant strategy of arming  E.g. Common resources: All better off if everyone conserve common resources. Each person dominant strategy = overuse resource  The noncooperative equilibrium may be bad (reduce welfare) for society and the players: E.g. Arms race game, Common resource game On the other hand, other noncooperative equilibrium may be good for society: E.g. Oligopolists trying to obtain monopoly profits. If they fail, quantity and price will be closer to optimal level (socially efficient level) for the society | | |
| Why Players Sometimes Cooperate  When the game is repeated many times, cooperation may be possible. These strategies may lead to cooperation:  1. Grim: If your rival cheats in one round, you cheat in all subsequent rounds.  2. Tit-for-tat:Whatever your rival does in one round (whether cheat or cooperate), you do in the following round. | | |
| Public Policy Toward Oligopolies  - Policymakers can sometimes improve market outcomes by inducing firms in an oligopoly to compete rather than cooperate  - Hence moving the allocation of resources closer to the social optimum  - E.g., implement antitrust laws - Sherman Antitrust Act, 1890 in US  - E.g., monitor for predatory pricing – firms charge prices that are too low, to drive other firms out of the market. (Grab-Uber merger) | | |
| How to measure the degree of competition in the market?  1) N-Firm Concentration Ratio: (higher ratio = less competition)  - the percentage of the market’s total output supplied by the N largest firms.  E.g., four-firm concentration ratio, five-firm concentration ratio, eight-firm concentration ratio.  2) Herfindahl-Hirschman Index (HHI): (higher HHI = less competition)  - square mrkt share of each firm competing in a mrkt and then sum the resulting numbers. It can range from close to zero to 10,000.  A market w HHI < 1,500 = competitive marketplace, HHI of 1,500 – 2,500 = moderately concentrated, HHI ≥ 2,500 = highly concentrated. | | |
| Constructive destruction | | | | Creative destruction (coined by economist Joseph Schumpeter in 1940s) = deliberate dismantling of established processes in order to make way for improved methods of production.  - Used to describe disruptive technologies such as Henry Ford’s assembly line, the railroads, and the internet.  - E.g., while incremental improvements to horse and buggy transportation continued to be valuable at the turn of the 20th century, the introduction of Ford’s Model T (a superior innovation) in 1908 drove these “technologies” out.  - E.g. Electrification, EV powertrains, |
| EV ecosystem | A diagram of an electrical system  Description automatically generated1. Adapt for incumbents or legacy automakers  E.g., GM (leads the US auto sales with 17% of mrkt) - Plans To Phase Out Gas And Diesel Cars By 2035.  - Plans to launch 30 new global EV by 2025 and plan for all its cars to be electric. (Variety expansion, keep brand loyal customers.)  - GM’s two primary markets are North America and China, with significant development in electric charging infrastructure  2. Horizontal integration (by internal expansion, acquisition or merger) & horizontal alliance (e.g. joint venture) are both growth strategies to gain tech, EOS, productive efficiency, mrkt share (& pricing power) within industry to get an edge over other competitors.  E.g., GM announced a deal w heavy-duty truck manufacturer Navistar International Corp. to supply hydrogen fuel cell units for a green semi-tractor model as a flanking strategy. | | | |
| 3. Vertical integration as a growth strategy to secure supply chain for production, and control over product quality. Forward (backward) integration occurs when a company buys the supplier or in-source towards the customer (raw material).  E.g., Tesla  - Integrated many production steps, from battery pack production to electric motor production, self- driving algos, central control system vertically and charging infrastructure.  - 1st foreign car manufacturer approved to operate fully independently while still retaining 100% ownership in China.  - Gigafactory in China 65% cheaper to build than its Model 3 production systems in the U.S.  - China (world largest EV market) is Tesla’s 2nd biggest market after the US. Locally produced cars in China qualify for govt subsides, and no import tariffs for Tesla’s customers  - China has rare-earth production needed for motors, lithium-ion battery pack production, electronic manufacturing capabilities, suppliers of automotive parts, and smart grids.  E.g., BYD  - Is a major battery and chip manufacturer, both for itself and as an OEM (original equipment manufacturer) to others.  - Uses lithium iron phosphate (LFP) chemistry in its Blade battery→ economically priced.  - Has a mobile phone manufacturing subsidiary, BYD electronics, and developing 5G communication to support the development of intelligent vehicles, & IOT - robots, intelligent speakers, sensors, communication modules, intelligent watches and earphones.  E.g., NIO  - Focus on consumer’s experience and loyalty – Brand value  - Offers “Battery as a service” through battery swap in 5 minutes, subscriptions and leasing options.  - Lower EV purchase price - Flexible range choice - Eligibility for govt subsidies for cars battery swap  - Made sales on Norway (country with highest EV adoption rate) and entering into Germany, Denmark, Sweden and the Netherlands.  E.g., Continental’s purchase of Argus Cyber Security and LG’s acquisition of Cybellum; Ford insourcing software  - To strengthen and enhance its capabilities in automotive cyber security for consumer experience | | | |
| 4. Vertical alliance (strategic partnership) to reduce production risk and/or cost  E.g., Tesla  - Long term supply agreement with Vale (Nickel producer) with mines in Brazil, Canada and Indonesia in May 2022. Seeking to diversify by sending delegation to Indonesia  E.g., VW, Huayou Cobalt and Tsingshan Group  - 2 partnerships for extraction of Ni and Co from Indonesia and for refining Ni and cobalt sulphates used for battery cathode production.  E.g., Skoda  - May 2022 will start battery production at its plant in Mladá, Boleslav for Skoda, VW, Audi and Seat brand cars. | | | |
| How strategic alliance in EV ecosystem evolves | | - Original longitudinal dataset composed of 281 alliances in the electric passenger vehicles market, initiated between 2000 and 2015.  - Paradigm shift: developing new car tech → creating charging infrastructure needs → supply chain management  *“Our analysis of the emerging electric vehicle ecosystem has therefore highlighted how incumbent focal firms (OEM formaly producing ICE vehicles), are driving the development of the network in terms of strategic alliances.”*  - More suppliers than OEMs in network, but... Dominant role of OEMs (Nissan, Renault Mitsubishi, BMW, Daimler) central in the network  - New EV entrant (Tesla, Reva Electric & Think( less central)  - Goals of OEMs’ alliances change over time, moving from development of new automotive architecture to delivery to end customers, from suppliers to complementors. | | |
| Trade-offs and distributional effects of subsidies | | | | China spend most on govt subsidies on EV in 2022, followed by Europe, US  Supporter:  - Subsidies as down payment for future economic gains, with corporates investing locally than abroad  - Support the construction of EV and battery plants which are capital intensive projects which require scale  - Create new jobs locally (average $50K subsidy per job)  - Positive spill-over effect on the EV ecosystem and datacentres - Mitigate climate change  Critic: - Distributional effects - taxpayers money directed to corporates |

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| Financing & Investing | | From EV ecosystem, 1. Adapt for incumbents or legacy automakers  E.g. Traditional ICE cars producers taking on BEV producers by investing in BEV and alternative tech such as renewables  Newly established companies need funding to grow.. Start ups can get govt subsidies, bank loans, bonds/equity venture capital investments, public offering  Strategies: - investment and divestment (dynamic management across time) - vertical and horizontal alliances | | |
| Raising funds - via Debt or Equity | | Debt financing involves borrowing of money and paying it back w interest  Equity financing involves selling a portion of a company's equity in return for capital  Modigliani-Miller Theorem (M&M Theorem, Capital Structure Irrelevance Theorem): In absence of taxes, bankruptcy costs, agency costs and asymmetric info and in an efficient mrkt, the enterprise value of a firm is unaffected by how that firm is financed  Deviations from M&M assumptions form the starting point of corporate finance:  - tax distortions (a significant component) - financial distress - informational frictions - moral hazards & agency conflicts  - inalienability of human capital & limited commitment - transaction costs - behavioural bias & inefficient capital mrkts  Inalienability of human capital & limited commitment & contract theory  *“In the late 1970s, Bengt Holmström demonstrated how a principal (e.g., a company’s shareholders) should design an optimal contract for an agent (the company’s CEO), whose action is partly unobserved by the principal. Holmström’s informativeness principle stated precisely how this contract should link the agent’s pay to performance-relevant information.”*  *“In the mid-1980s, Oliver Hart made fundamental contributions to a new branch of contract theory that deals with the important case of incomplete contracts. Because it is impossible for a contract to specify every eventuality, this branch of the theory spells out optimal allocations of control rights: which party to the contract should be entitled to make decisions in which circumstances* | | |
| Corporate finance | | Planning, developing and controlling capital structure of a business  To incr organizational value and profit through optimal decisions on investments, finances as well as dividends  To match capital invesments needs w funding requirements of a business using a favourable capital structure  To maximise valuf of firm: | | |
| 1) Invesment Decisions: invest in assets earning returns > min hurdle rate  Hurdle rate = riskiness of invesment & equity-debt mix to fund it  Return = magnitude and timing of cashflows and other implications of investment | 2) Financing Decision: finding right type of debt & right mix of debt & equity to fund operations  Match the tenor (duration) of the assets | 3) Dividend Decision: in absence of suitable invesment meeting the hurdle rate, return cash to owners of the business (divest)  Amt of cash to payout vs retain depends on current & potential invesment opp  How to return cash depends on owners preference (for dividends or share buyback) |
| Corporate Balance Sheet | | A diagram of a company's company's company's company's company's company's company's company's company's company's company's company'  Description automatically generated | | |
| Financing Decision | | Debt is least information sensitive as it is senior to equity, i.e., when money flows in, debt gets paid first.  Equity is also known as residual claims. It is the right of a shareholder to the profit of a firm after all prior obligations have been paid.  Debt vs equity decision, holding all else constant :   |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | | Issue | Flotation costs | Interest rates | Tax rate | Earning Volatility | Business Growth | % Debt in Capital Structure | % Equity in Capital Structure | | High | Issue Debt | Equity | Equity | Equity | Equity | Equity | Debt | | Low | Equity | Debt | Debt | Debt | Debt | Debt | Equity | | | |
| Investment decision | | Time Value of money: Need for tools to be able to compare the values today and in the future.  Financial decisions often require combining cash flows (CFs) or comparing values  Never add/subtract CFs from different time periods without first converting them to a common time unit  Assuming the discount rate is r% per year, the 3 rules are:  Compare or combine ONLY values at the same point in time  To move a cashflow forward, compound it – to get future value of a cash flow: FVn = C \* (1 + r)n  To move a cashflow backwards, discount it – to get the present value of a cash flow: PV = C / (1 + r)n.  1/(1+r)n aka present value factor or discount factor  To make decision: 1) Choose largest future value (future value analysis) OR 2) Present value analysis (largest non-negative PV) OR  3) Net Present Value analysis (largest net present value): NPV = PV(B) - PV(C) (B = benefits, C = cost)  - If only 1 new potential project and its impacts are calculated relative to the status quo, should select if NPV > 0  - If multiple projects, choose project w highest NPV as long as this project's NPV > 0 | | |
| Interest is compounded when an amt is invested for a num of years and the interest earned each period is reinvested.  Simple interest = same amt of interest. Interest payments are not reinvested | | |
| Cash flow might differ from year to year. Have to take into account benefit of each unique year and multiply by associated discount factor. Bt = benefits at year t. n = lifespan of project. PV(B) =  Similarly, NPV = PV(B) - PV(C) =  Alternatively, compute net benefits for each year. NBt = Bt - Ct. Then NPV =  E.g. initial cost = $325 000, maintenance = $20 000 per year, benefits = $100 000 per year, after 5 years sell for $20 000, discount rate = 7%   |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | Year | Benefit | Cost | PV of benefits | PV of cost | PV | | 0 | 0 | 325000 | 0 | 325000 | -325000 | | 1 | 100000 | 20000 | 93457.94 | 18691.59 | 74766.36 | | 2 | 100000 | 20000 | 87343.87 | 17468.77 |  | | 3 | 100000 | 20000 | 81629.79 | 16325.96 |  | | 4 | 100000 | 20000 | 76289.52 | 15257.9 |  | | 5 | 100000 | 20000 | 85558.34 | 14259.72 |  | | Sum of PV |  |  | 424279.47 | 407003.95 |  |   Since NPV = 424279.47 - 407003.95 > 0, project is implemented | | |
| Mutually Exclusive Projects. Select project w highest NPV   |  |  |  |  |  | | --- | --- | --- | --- | --- | | Project | Initial investment | First-year cash flow, C | Growth Rate, G | Cost of capital, r | | A | 250000 | 55000 | 5% | 7% | | B | 400000 | 80000 | 6% | 7% | | C | 500000 | 175000 | 5% | 7% |   PV of a growing perpetuity = C/(r - g). For e.g. choose C (highest NPV)  NPV(A) = -250000 + 55000/(7 - 5) = 2500000. NPV(B) = -400000 + 80000/(7-6) = 7600000. NPV(C) = -500000+175000/(7-5) = 8250000. | | |
| Intrinsic value of assets | Value of an asset is the present value of expected cash flows on that asset over its expected life.  Value of asset =  - Factors that do not affect the cash flows or change the risk (hence the discount rates) do not affect the value.  - For an asset to have positive value, its NPV must be positive, i.e its expected cash flow > 0 at some time over the life of the asset.  - The intrinsic value of an asset may differ from its price.  - Discount rate must reflect current market conditions – e.g., risk-free rate, equity premium, default spread.  - Discount rate should be consistent with the riskiness and type of cash flows being discounted. E.g., cost for equity for discounting dividends & cost of capital for free cash flows to firm respectively. | | | |
| ESG investing | | Some investors are applying these non-financial factors as part of their analysis process to identify material risks and growth opp.  While ESG ratings are meant promote greater transparency and incentivize companies to improve their performance by making them accountable for their negative externalities, it is often profitable for a business to externalise costs  Unlike credit ratings, ESG ratings by different rating companies are poorly correlated, even if E, S and G scores are considered separately.  Measuring emissions:  Scope 1 - a company’s day-to-day operations,  Scope 2 - those from its energy suppliers e.g. electricity. Out of ≈ 10,000 firms in its world index, < 40% reported scope 1 & 2 emissions.  Scope 3 – covers the entire supply chain, from extraction of raw materials through suppliers to end users; account for 90% of emissions in some industries. Supplier data may be hard to find. Consumer data may depend on estimates. | | |
| ESG investing and its discontents: firms’ perspective  Rating based on business models; what firms sell does not matter as long as it is done sustainably. Tobacco and alcohol companies feature high ESG rankings, and many “green” funds invest in fossil fuel companies.  Greenwashing = company's practice of amplifying their ESG efforts to accrue its benefits without doing any of the meaningful work. | | |
| ESG investing and its discontents: intermediaries & individual investors  - ESG has become a gravy train for the investment industry. Charge higher fees for ESG-related investments than for non-ESG ones.  This could be due to: - Size effect (core S&P 500 fund is ten times the size of ESGU index funds, enabling lower fees for non ESG.)  - Milking the warm-glow and/or virtue signalling effect of ESG investing derived by the investors due to their preferences  - Reverse causality - do successful firms embrace ESG or does ESG make firms successful? | | |
| ESG investing and its discontents: individual investor’s behaviour – mood & risk preferences  Garel, Fernandez-Perez & Indriawan (2022) decided to study how emotions play a role in determining people’s preference for environmental, social and governance-oriented investments.  Hypotheses: 1. based on the idea that sustainable assets are generally less risky, people with “a lower mood” tend to be more risk-averse, hence buy more sustainable assets;  2. based on the notion that “a positive mood” promotes pro-social behaviours and greater altruism, people with a positive mood buy more sustainable assets.  Findings: People with a worse mood to devote a larger proportion of their money to sustainable assets because of the perception that they are less risky investments. | | |
| ESG investing and its discontents: regulators  Regulators - mission creep into the boardroom? Rationale: 1. climate change is too big a risk to the financial system to deal with under the old rules & 2. shareholders want more information.  Started with the Sarbanes-Oxley Act of 2002 - a law the U.S. Congress passed on July 30 of that year to help protect investors from fraudulent financial reporting by corporations  Then, Dodd-Frank act of 2010, which mandated reporting on executive pay.  Now, ESG-related proposal from the Securities and Exchange Commission (SEC) to force companies to disclose climate-related info.  This happens on both sides of the Atlantic, yet standards are not identical. The European Union is pushing for another set of standards, the corporate-sustainability reporting directive, to become law in its 27 member countries by the end of this year.  Profit-seeking companies have too little incentive to save the planet. | | |
| ESG investing and its discontents: politicians & CEOs : focus only on profits, stakeholder capitalism, profits will improve in long run... | | |
| ESG investing and its discontents: rationale  Value of a firm = present value of the expected cash flows to the firm discounted back at the cost of capital.  If the cash flows to the firm are held constant, minimising the cost of capital will maximise the value of the firm.  Hence, giving rise to the role of investors’ activism, ESG investing→ making firms internalise their carbon emissions and other externalities  i.e. make polluters pollute less by dumping their shares, hence raising cost of capital for polluters, and impeding new investment by them.  Caveat: this does not work if there is an abundance of alternative private cash willing to buy up those shares | | |
| Green assets: Green bonds in SG | | |
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