10th Joint Bank of Canada and European Central Bank Conference: The Future of Global Trade and Implications for Monetary Policy

Industrial Policies for Multi-Stage Production

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Harvard University

Based on joint work with Keith Head, Thierry Mayer, and Chenying Yang

Part I

Introduction

Industrial Policies with Multi-Stage Production and Endogenous Facility Location Choice

How do subsidies and trade restrictions shape global supply chains?

- Industries targeted by industrial policies often share key features
- High fixed costs and competing locations
  $\rightarrow$ Most locations won't receive plants (substitutes)
  - There is a core input that drives costs of the downstream product (complements)
- Understanding the impact of those policies is challenging
  $\longrightarrow$ Indirect effects via impact on plant location choice

Main Takeaway:

- Changes in plant location choices drastically affect how we quantify the impact of industrial policies (and sometimes even affect their direction!)

Application to the Auto Sector

1. Regional content restrictions under USMCA: compliance decision and assembly location choice (under constant returns to scale)
2. Facility location choice with multiple part stages and increasing returns to scale (high fixed investment costs)
   - Industrial policies: Subsidies with/without content restrictions

Part II

Regional Content Restrictions: Compliance Decision and Assembly Location Choice

Rules of Origins

- Free trade areas (FTAs) and rules of origins (RoOs)
  - Most prominent recent changes in trade policy involve FTAs
  - WTO rules allow for RoO to address external tariff imbalances
  - ... but those imbalances bear tenuous – if any – links to negotiated RoOs
    - Why did US push Canada and Mexico to drastically increase the RoO for cars in the new USMCA agreement (US car part tariffs are lower)?
    - Why is the EU and UK negotiating RoOs when most of the tariffs are harmonized?
  - So RoO appear to be a popular protectionist tool
    - Also used beyond FTAs...

Rules of Origin and Endogenous Location Choice

Head, Mayer & Melitz (2024): "The Laffer Curve for Rules of Origin"

- RoOs induce firms to reorganize their production networks
- ... and may often lead to unintended and undesired consequences...

Recap:

- NAFTA renegotiation to USMCA for autos
  - Implementation starting in 2020
  - Progressively raises North American part requirement for motor vehicles from 62.5% to 75%

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What is the Impact of Tighter Rules of Origins in the renegotiated NAFTA/USMCA?

Policy maker faces trade-off when evaluating protectionist policies:

- Benefit to protected domestic industry vs cost to consumers
  - Cost increases $\longrightarrow$ price increases (also through higher markups)
  - Reduced consumption choices

- However, in some cases the protectionist policies have unintended and undesired consequences
- ... And both domestic industry and consumers can be negatively affected

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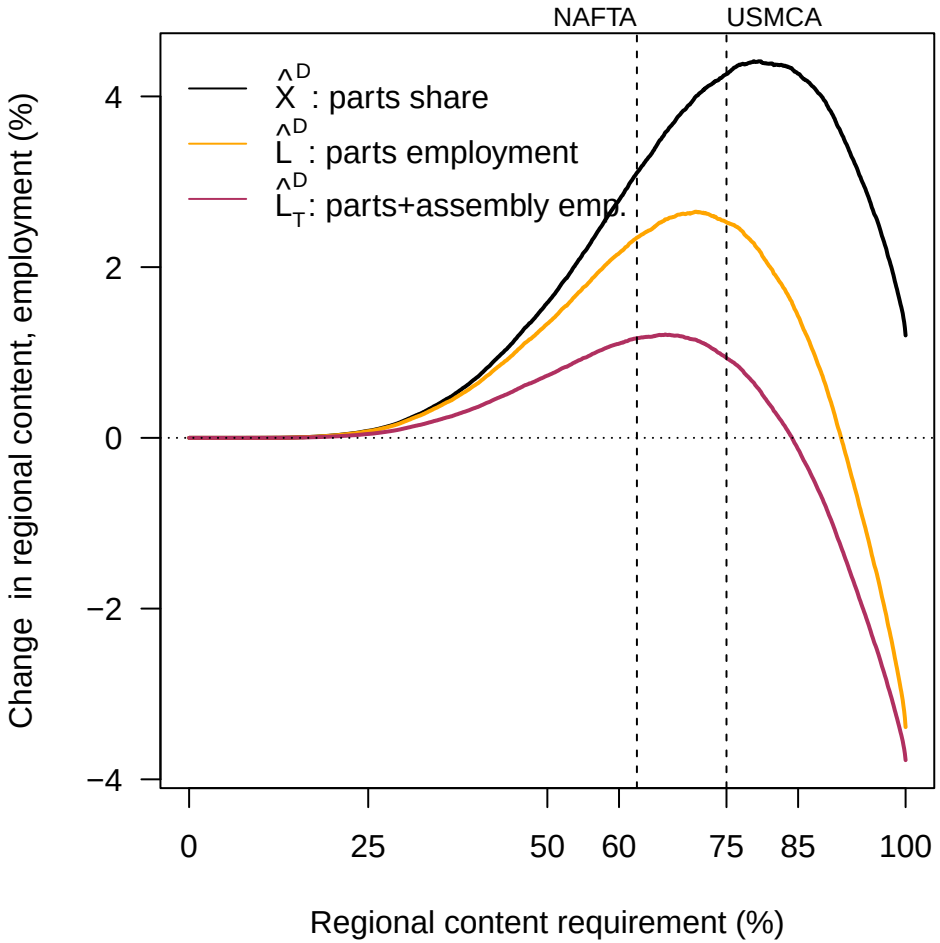
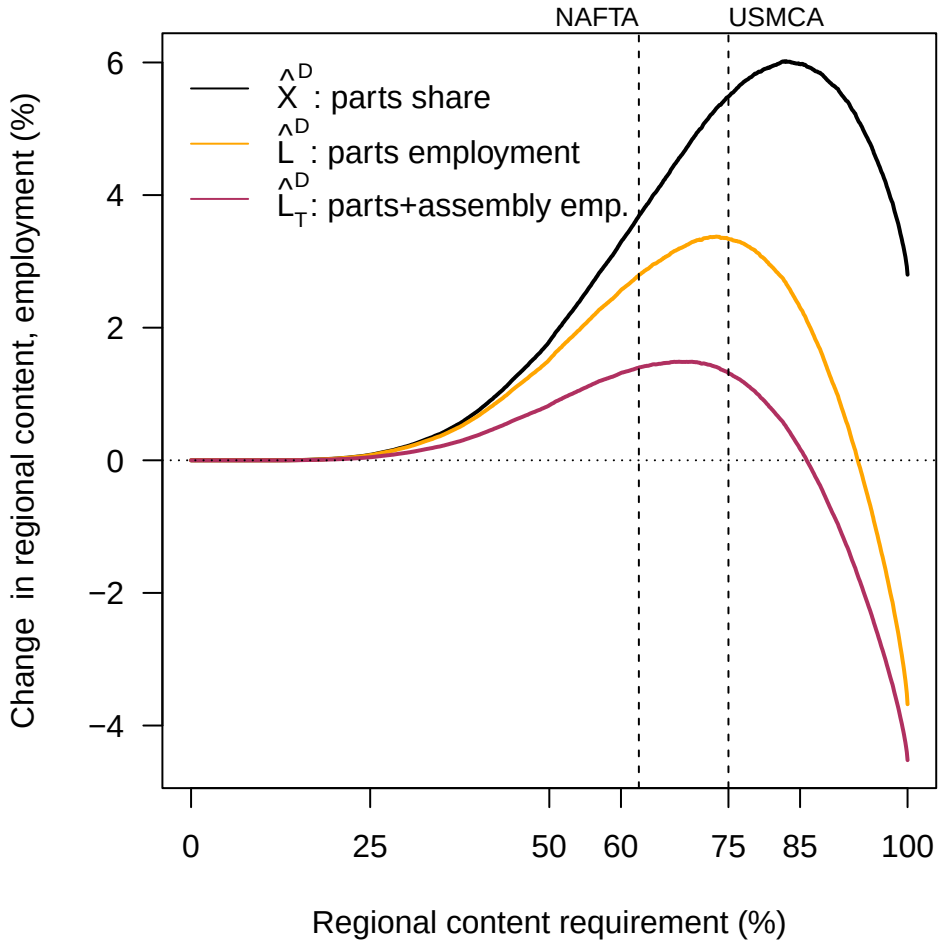
No Assembly Relocation: NAFTA vs UCMCA for US Assembly Locations



Cars



Trucks

Assembly Relocation

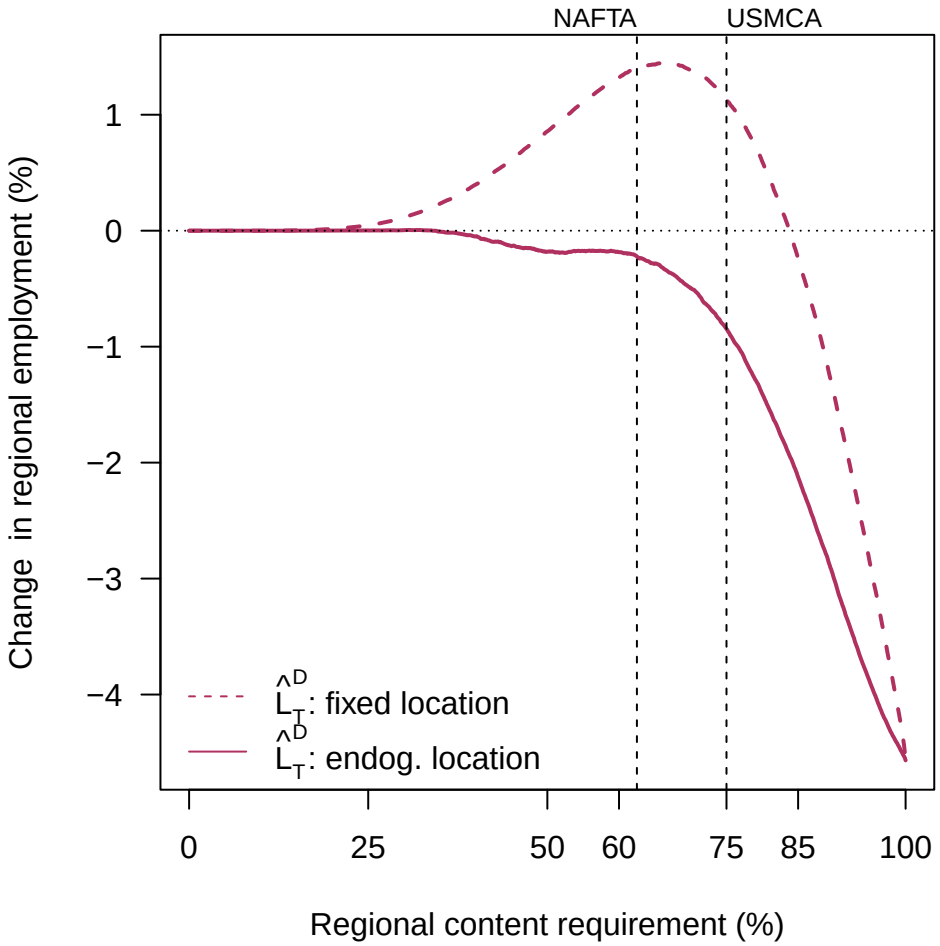
- Negative consequences of RoOs are magnified when assembly can relocate
- Firms then also re-organize their production network based on the new location of assembly
  - Assembly moves away from Mexico and Canada towards US but also outside of North America

Auto Part Sourcing (Recap)

- Share of parts sourced within NAFTA varies drastically by location of assembly:

	Assembly location:	
HQ country	NAFTA	NON-NAFTA
USA (GM, Ford)	71.1%	11.8%
Japan	60.1%	4.0%
Germany	45.8%	2.6%
Other	64.5%	3.2%

NAFTA vs USMCA: North American Auto Employment



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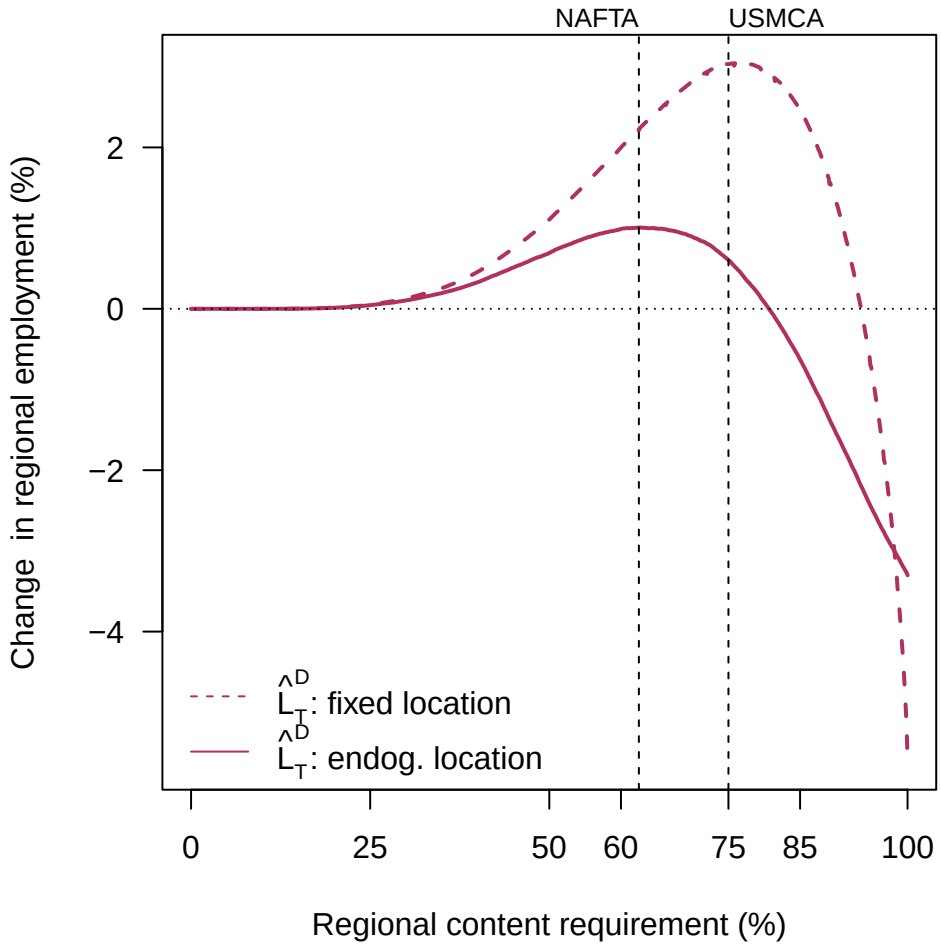

Trucks

Part III

Multi-Stage Facility Location Choice with Increasing Returns

Discrete (Facility Location) Choice vs "Smooth" RTS

Head, Mayer, Melitz & Yang (2024): "Industrial Policies for Multi-Stage Production: The Battle for Battery-Powered Vehicles"

- Add fixed costs for both assembly and parts (batteries)
- Impact of industrial policies:
  Open/Close decisions (facility location choice) $\longrightarrow$ "jumps" in "delivered marginal cost"
- But the direction of those "jumps" is not determined by parameter values

- For example:
  - Industrial policy in one region can move delivered MC up or down in other regions
  - Trade restrictions can move delivered MC up or down

$\longrightarrow$ Quantitative policy evaluation requires estimation of "when/where" jumps occur, their direction, and magnitude

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Solving Facility Location Choice: Substitutes or Complements?

- Within production stage: substitutes.
- Across production stages: complements
- $\longrightarrow$ This problem is neither submodular (locations are substitutes) nor supermodular (locations are complements)
- With a continuum of inputs, squeezing/pruning algorithms cannot be used. $\longrightarrow$ This problem is NP-hard: $2^{L.K}$ combinations (L locations, K stages)
  - Computation time for each combination increases proportionately with number of products and destinations

Solving Facility Location Choice: New Computational Method

- In our application to the battery electric vehicle industry (BEV), inputs are discrete (battery cells), and stages of production (including final assembly) are observed
  - This reduces the problem to a choice of L^K paths across the K stages of production for a given BEV model sold in a given destination
    ... But paths are inter-dependent across models and destinations
  - Key difference: discrete set of inputs and single sourcing (not input substitutability)

Theoretically, this problem is still NP-hard, but in practice it can be quickly solved (global optimum) using advances in optimization techniques for linear programs with integer constraints (Mixed Integer LP)

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Solving Facility Location Choice w Integer Linear Programming

- Recasting the facility location choice problem as a (mixed) integer linear program has been studied extensively in the operations research (OR) literature – but has not received much attention in the economics literature
- It efficiently solves problems that involve:
  1. Multiple stages of production with no restrictions on complementarity or substitution between facilities (super vs sub modularity)
  2. Flexible specification of fixed costs across groups of products, locations, and stages of production
  3. Endogenous market entry to multiple markets
  4. Many different demand and production cost structures (including trees)
- And this solution method dovetails nicely with simulation-based estimation (SMM) and policy counterfactual analysis

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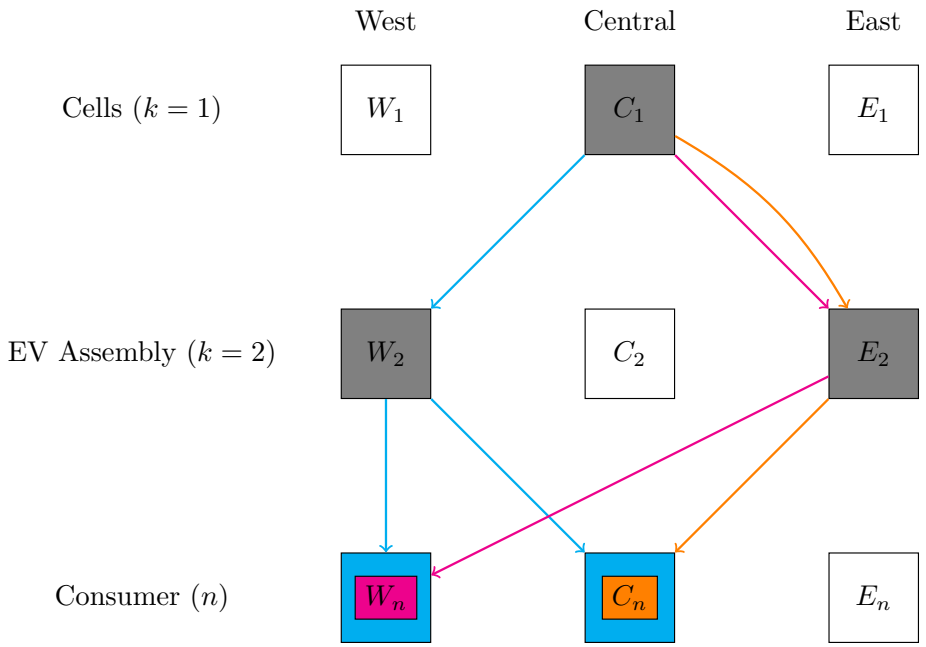
Optimization Over Paths



- Firm chooses which models m to sell to each market n
  - Subject to market entry/access cost $\phi_{mn} \longrightarrow z_{mn} = \{0, 1\}$
- Firms chooses which facilities to open at each production stage k
  - Subject to facility fixed cost $\phi_{\ell k} \longrightarrow y_{\ell k} = \{0, 1\}$
- Firm chooses optimal path ℓ_{mn} $\forall m, n$ through open facilities

Chosen path ℓ_{mn} is associated with delivered marginal cost $c(\ell_{mn})$ and variable profit $\pi(c(\ell_{mn}), A_n)$ for model m sold in n with market demand A_n
$\longrightarrow$ Single index aggregator A_n is consistent with many preference specifications (including CES and Logit)

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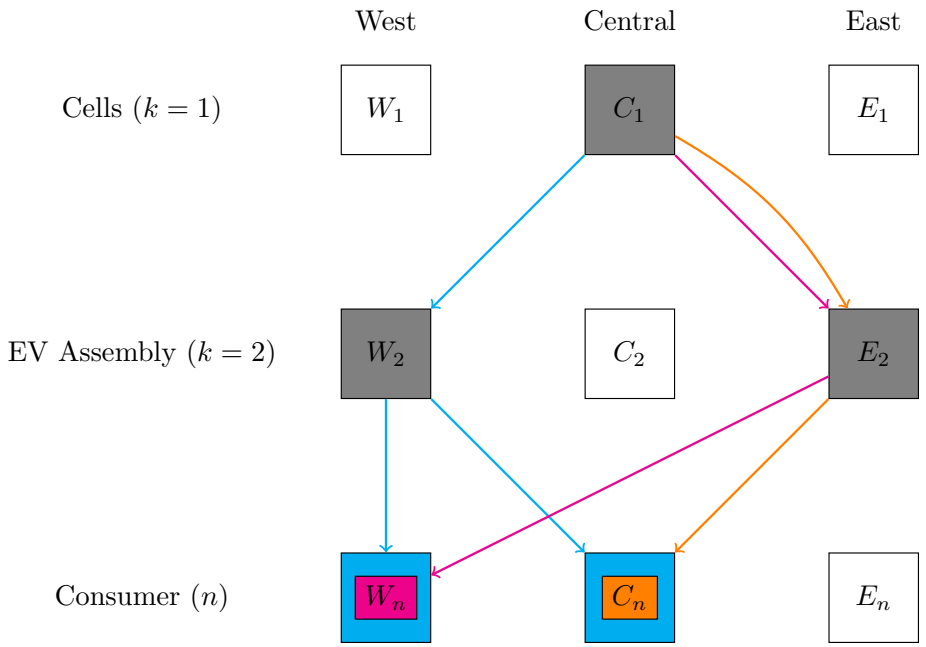

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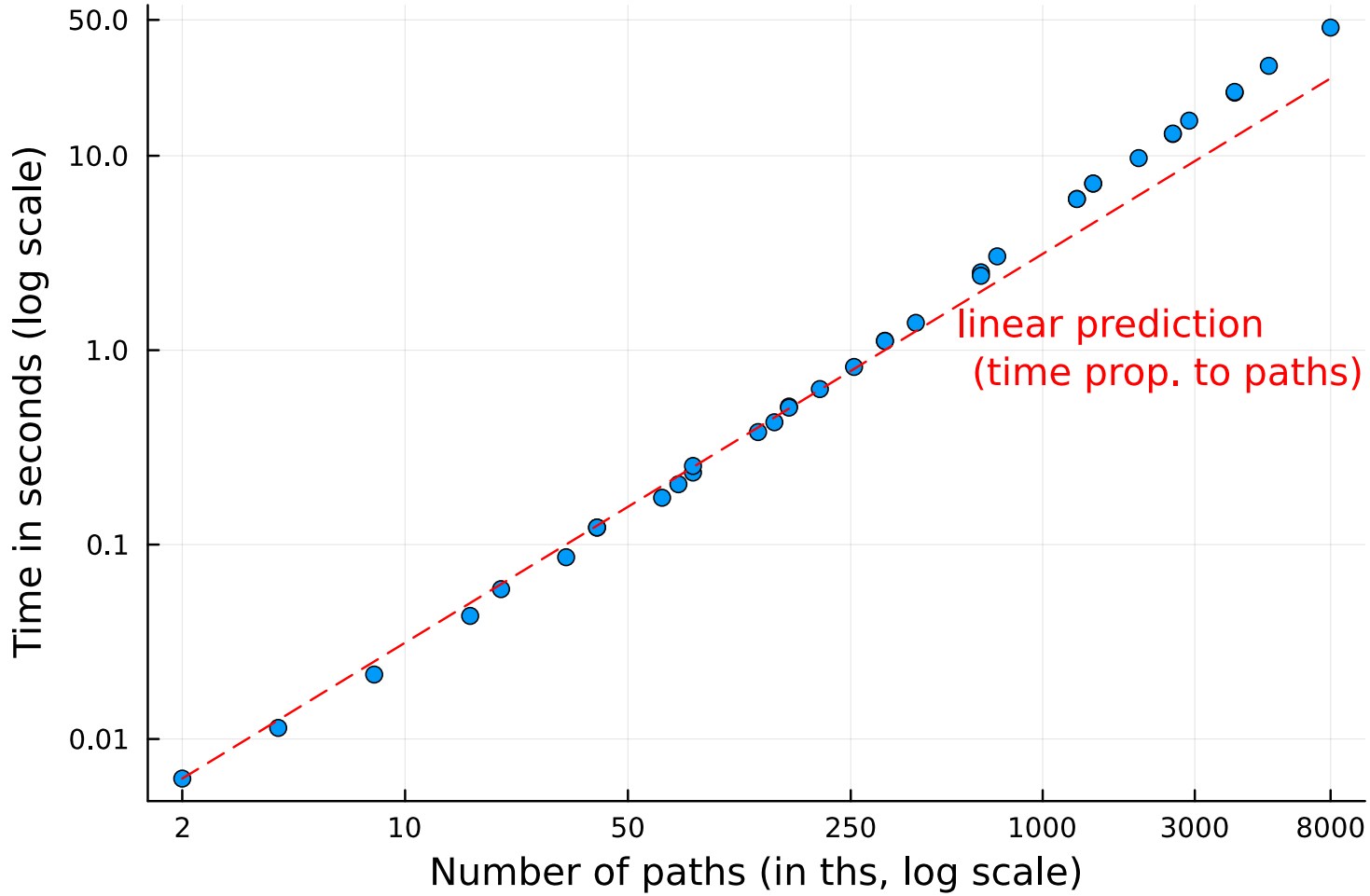
MUFLP with Multiple Production Stages ($K > 1$): Computation time is approximately linear in number of paths



$$\#\ \text{Paths} = L^K \times N \text{ vs Brute force} \propto 2^{L.K} \times N$$

Necessary Industry Characteristics for this Framework

- Constant marginal costs
- Inputs from different plants are perfect substitutes if all dimensions of the product are specified (need dis-aggregated sourcing data)
- Plants are "uncapacitated" : no long run constraints on output

$\longrightarrow$ Single sourcing

- No bargaining between buyer and supplier

$\longrightarrow$ Single decision maker

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High Up-Front Investments (Especially for Batteries)

Tesla Investing $3.6B For Battery And Semi Production In Nevada

$4.9B electric vehicle battery plant announced for Windsor, Ont.

GM Plans Biggest Manufacturing Investment Ever In Its Home State For EV, Battery Production

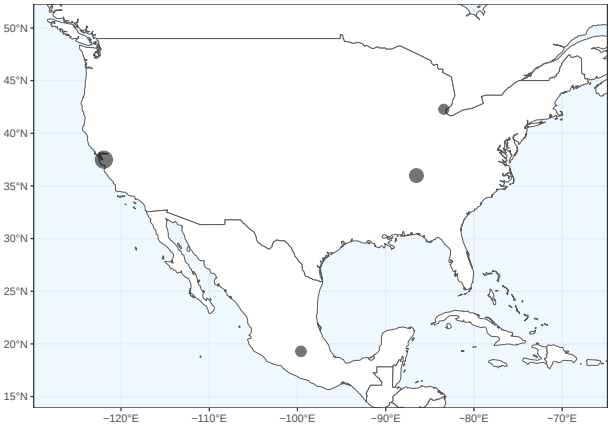
FORD TO LEAD AMERICA'S SHIFT TO ELECTRIC VEHICLES WITH NEW MEGA CAMPUS IN TENNESSEE AND TWIN BATTERY PLANTS IN KENTUCKY; $11.4B INVESTMENT TO CREATE 11,000 JOBS AND POWER NEW LINEUP OF ADVANCED EVS

Toyota's North Carolina Battery Plant Investment Nears $14B

VW breaks ground on new battery factory, will invest €20b into "PowerCo" spinoff

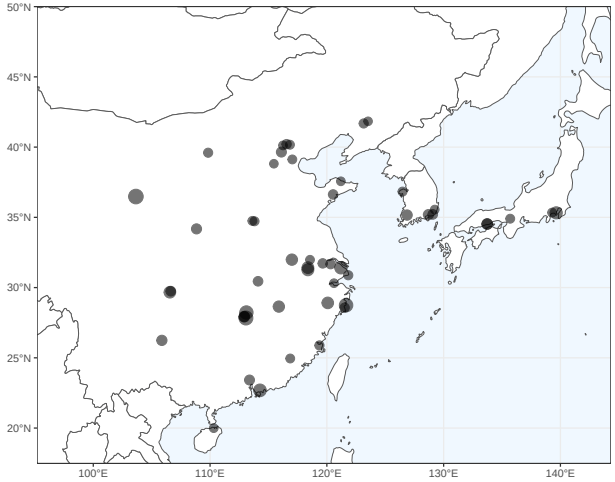
Assembly Location Expansion: 2015-2022

4 Assembly Plants in 2015, Total 75k BEVs

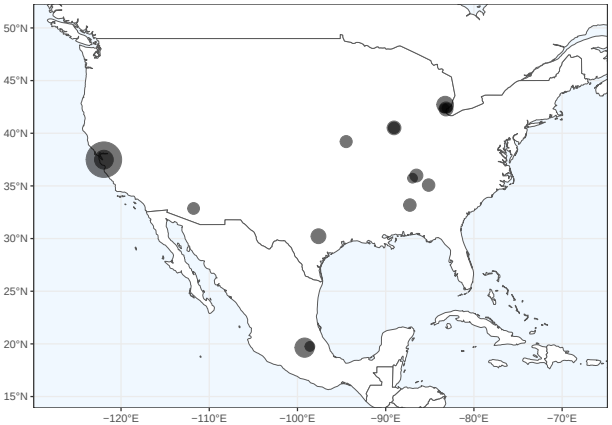


16 Assembly Plants in 2015, Total 80k BEVs

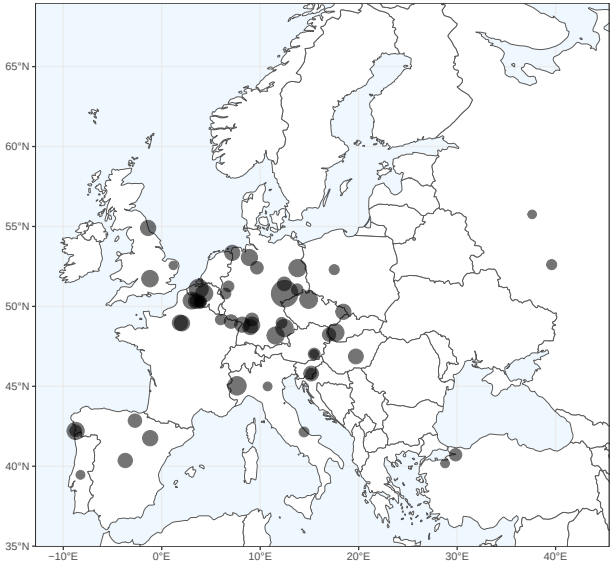
52 Assembly Plants in 2015, Total 175k BEVs



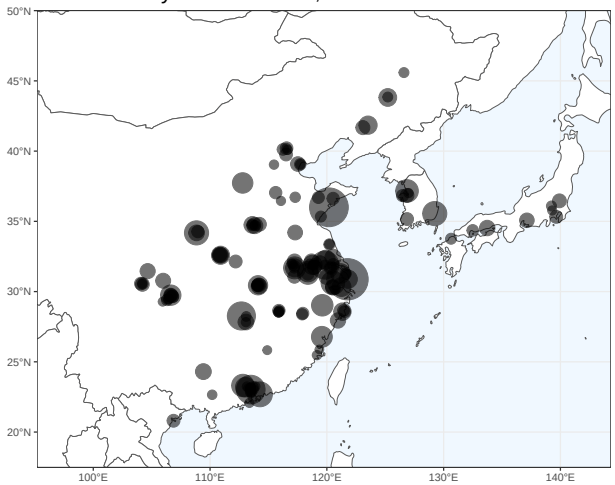
17 Assembly Plants in 2022, Total 812k BEVs



52 Assembly Plants in 2022, Total 1392k BEVs

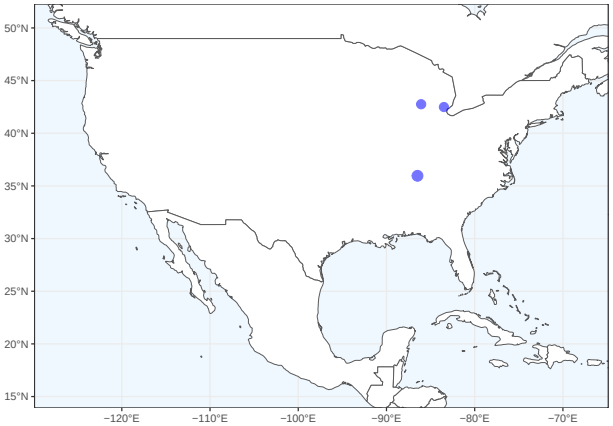


170 Assembly Plants in 2022, Total 5893k BEVs



Cell Production Expansion: 2015-2022

3 Cell Plants in 2015, Total 0.6GWh



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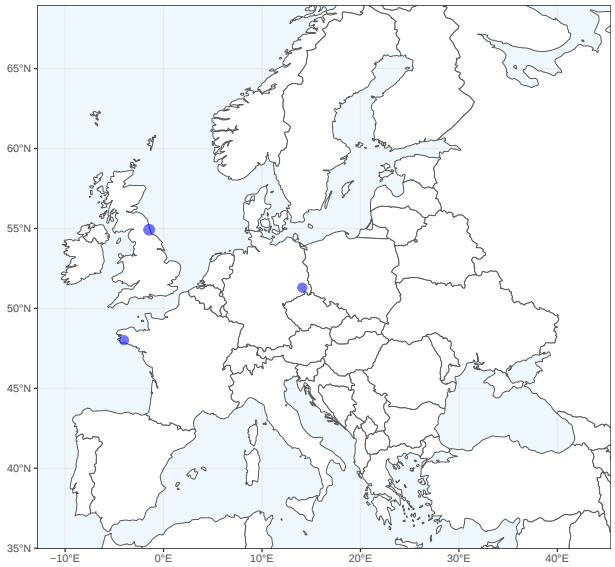
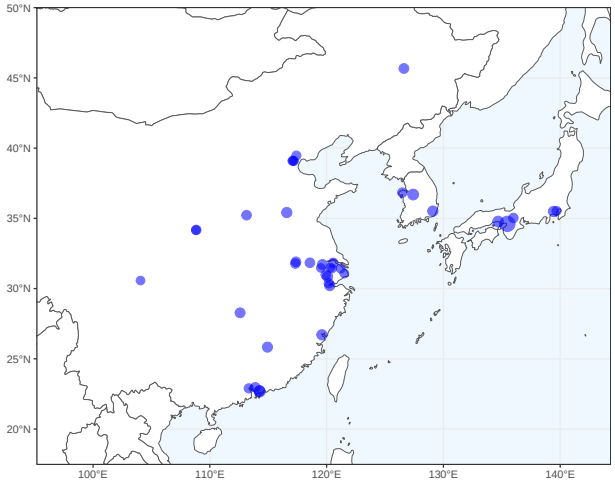
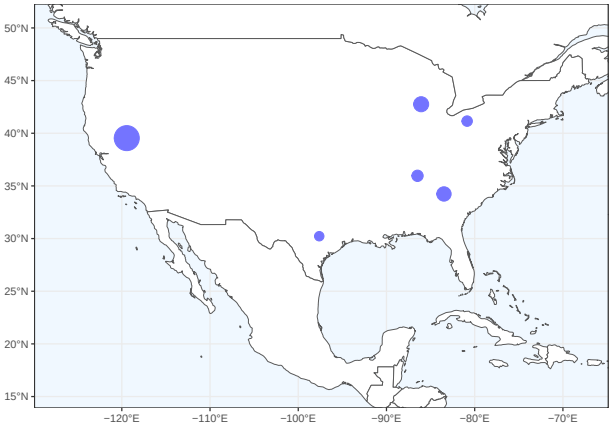


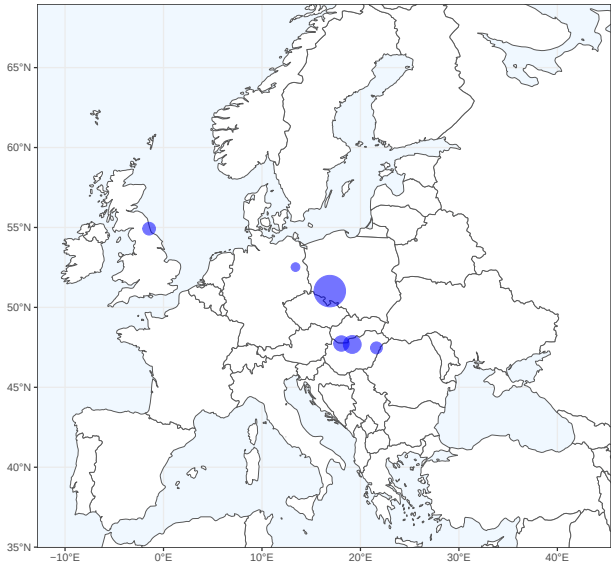
39 Cell Plants in 2015, Total 9.8GWh



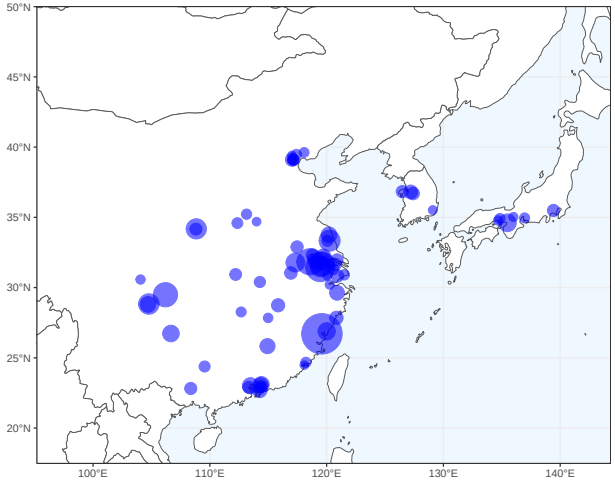
6 Cell Plants in 2022, Total 34.1GWh



6 Cell Plants in 2022, Total 64.8GWh

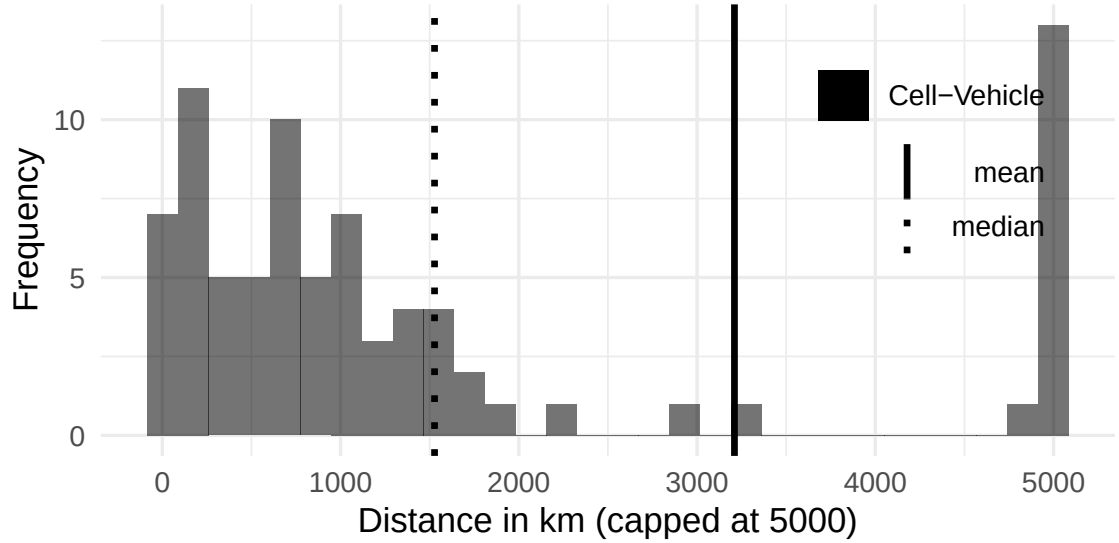


74 Cell Plants in 2022, Total 374.2GWh

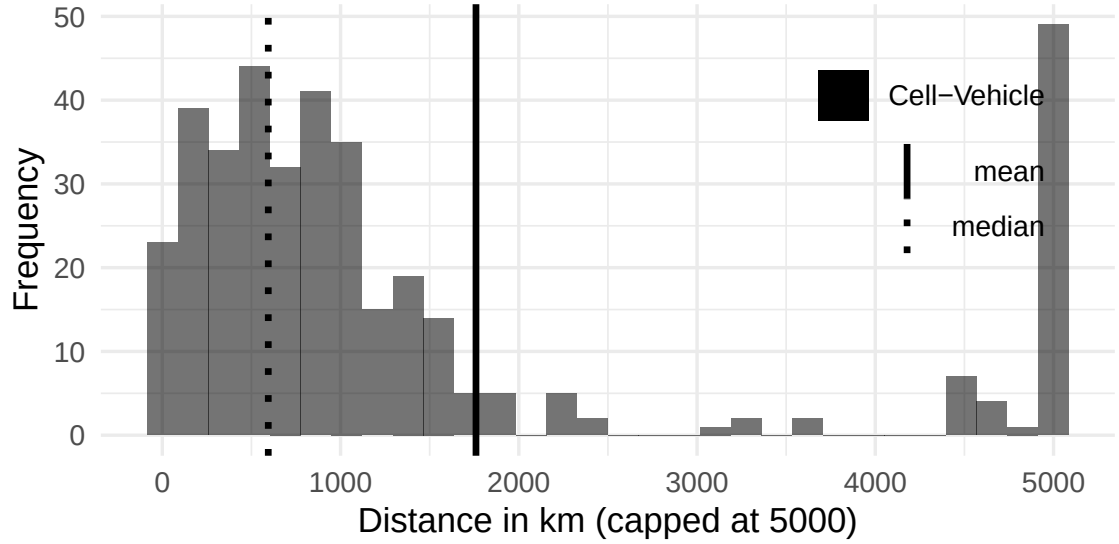


Proximity Matters for Cells and Vehicles

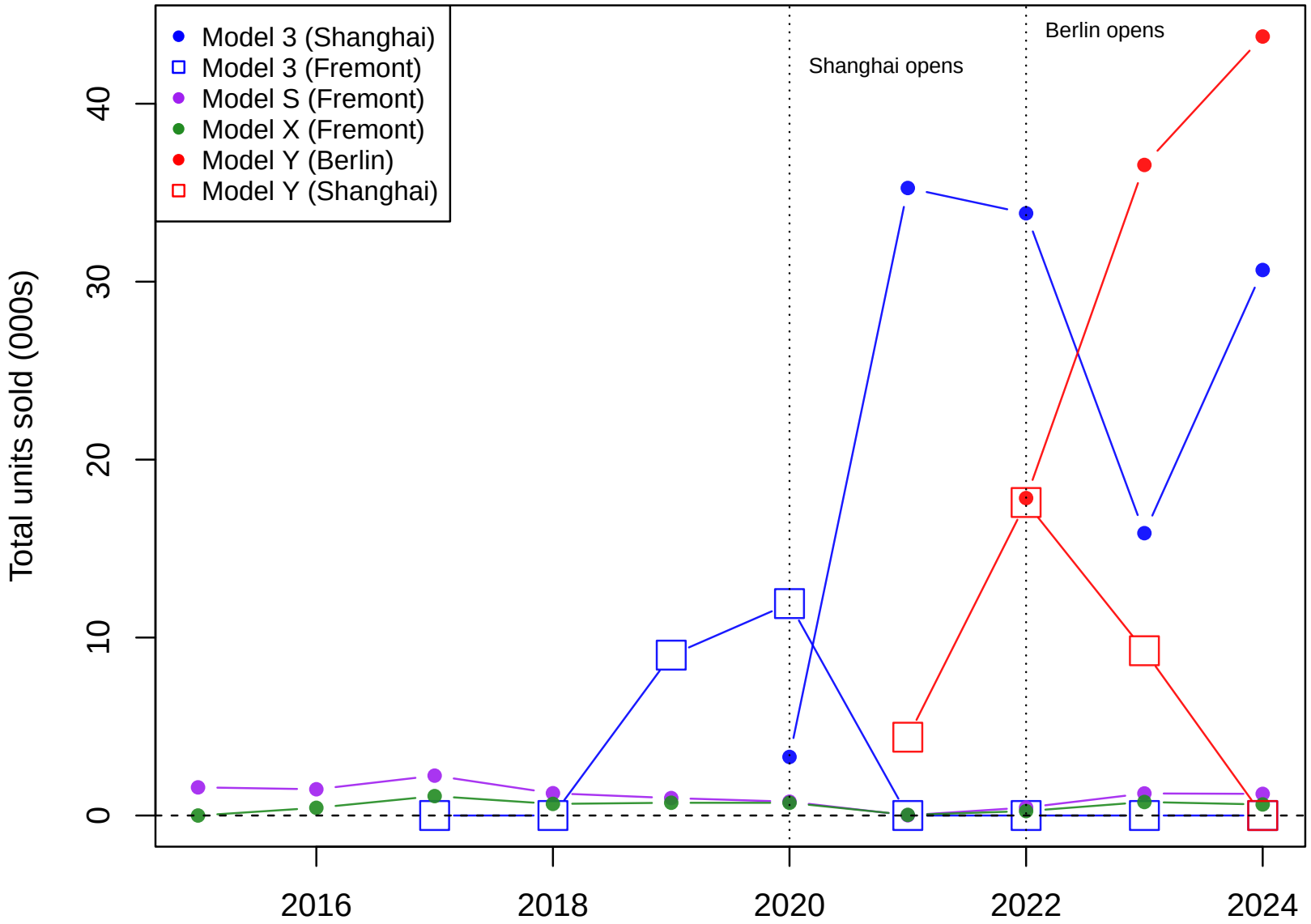
2015



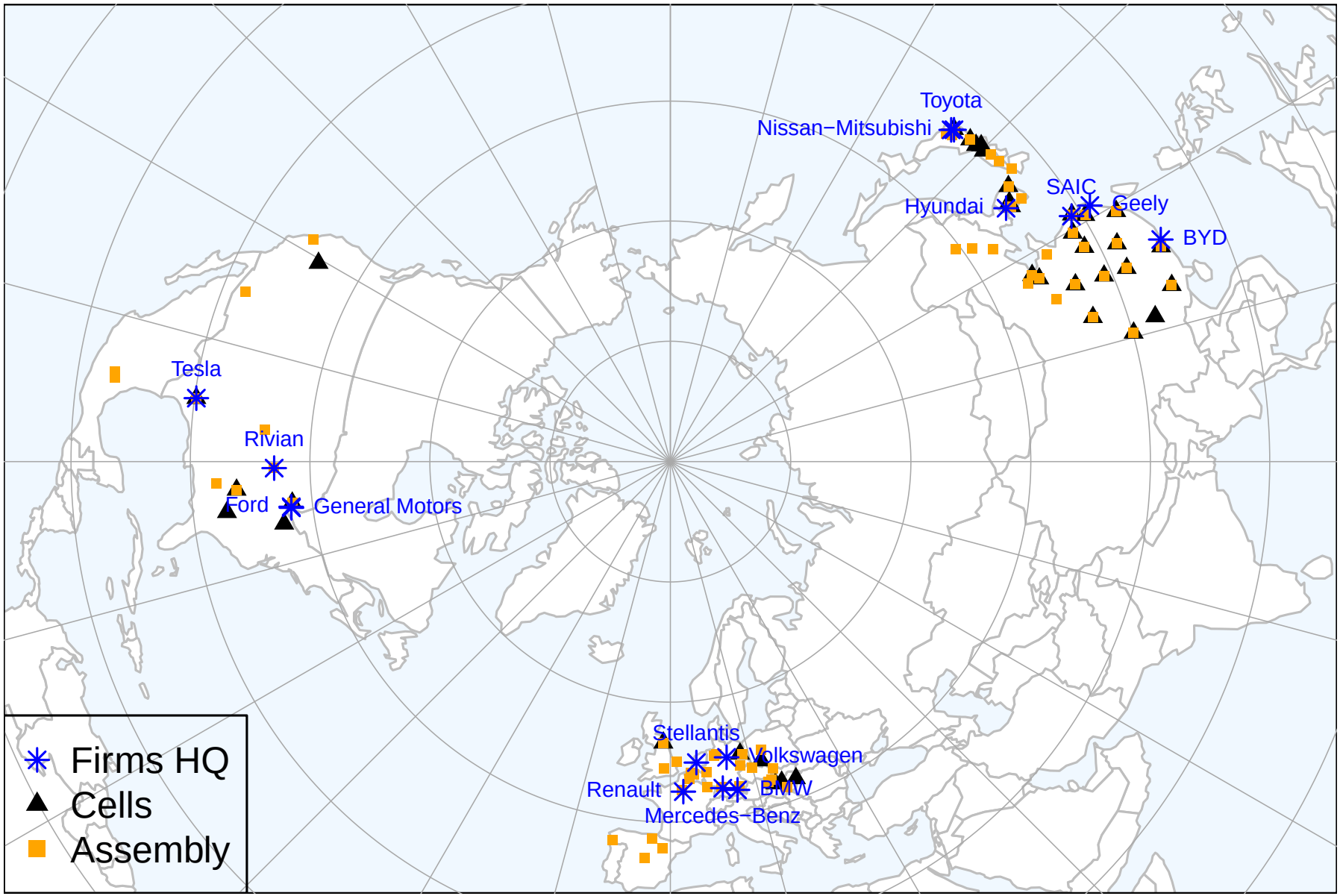
2022



Multi-Sourcing is Transitory or Across Models/Trims: German Tesla Multi-Sourcing



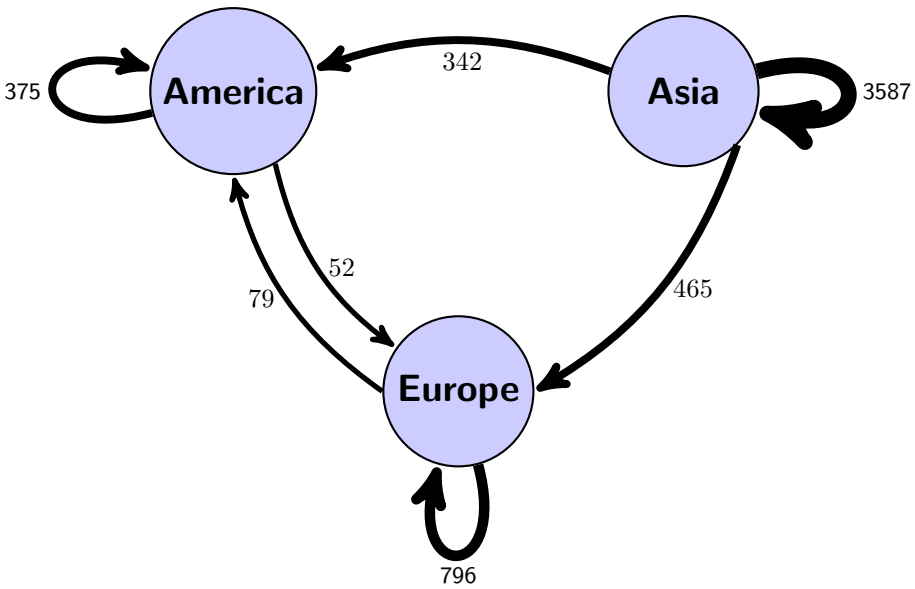
Top EV Firms and Their Location Alternatives



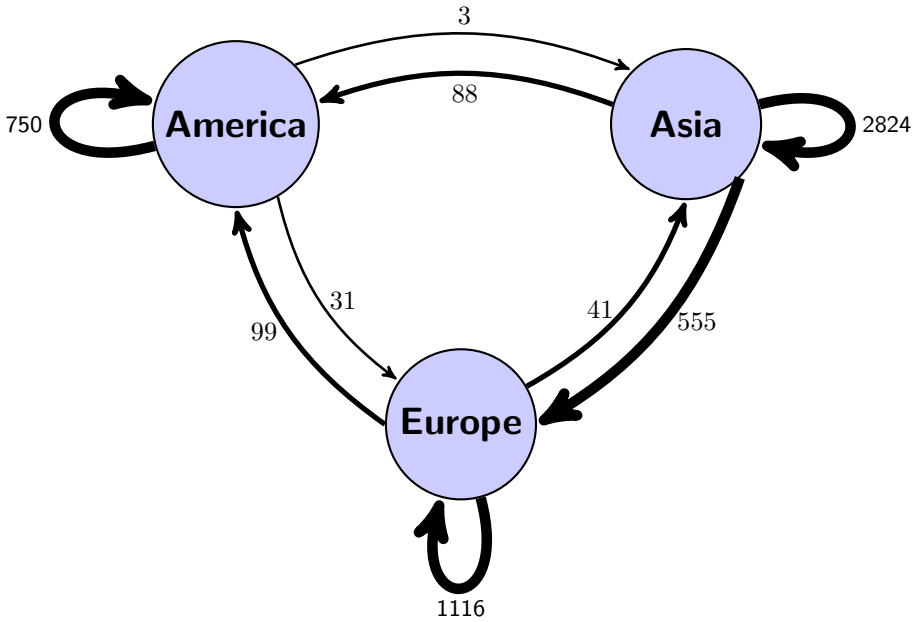
Total Configurations: $2^{24+60} \longrightarrow$ median locations/groups: 24 (cell) 60 (assembly)

Cross-Continental BEV Flows

Cells (000s of vehicles)

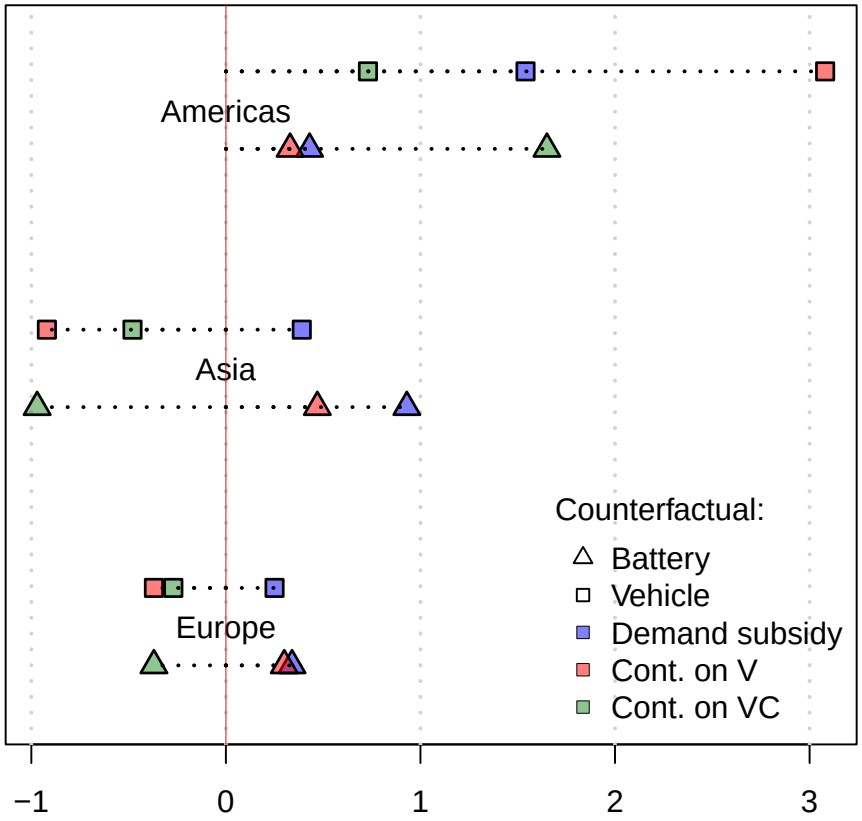


Vehicles (000s)



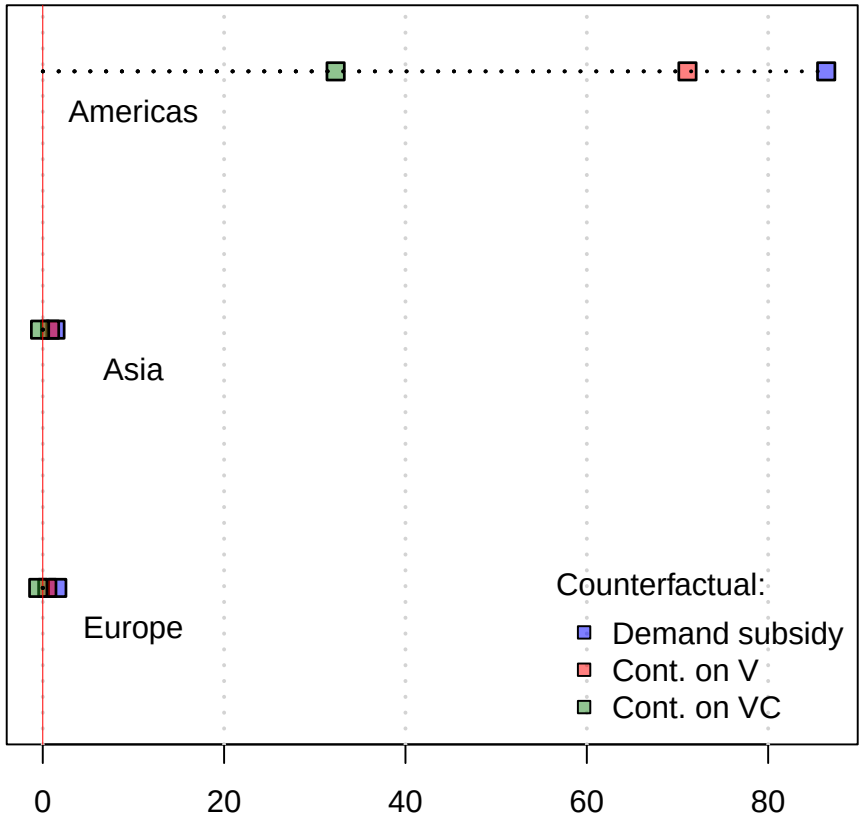
Predicted Impact of NA BEV Subsidies

Production Lines



Change in number of production lines wrt baseline

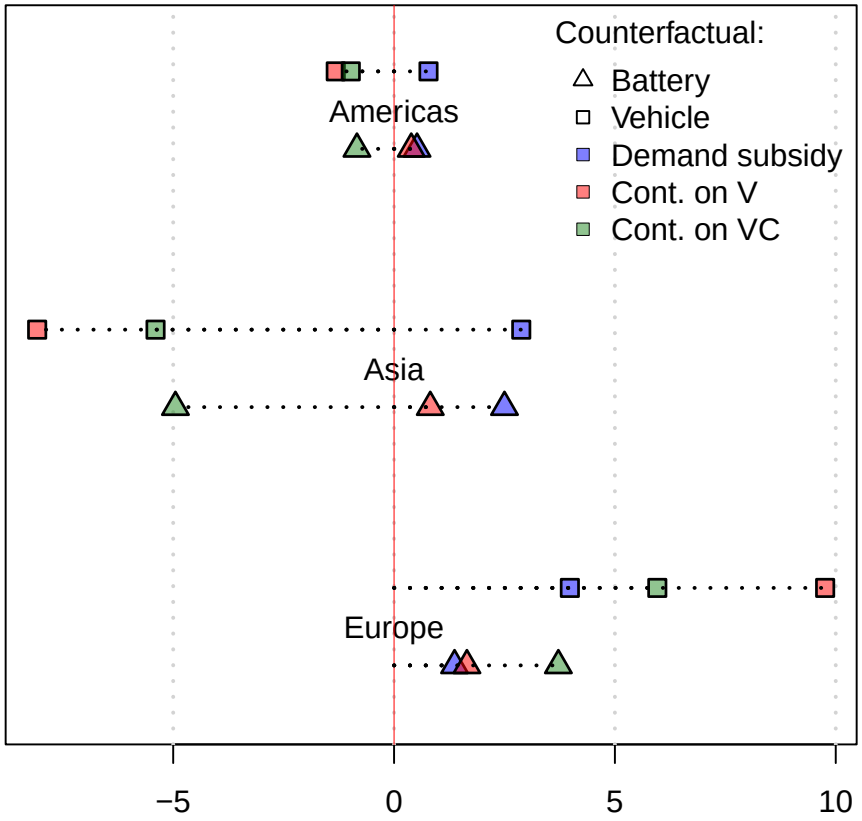
BEV Expenditures



% change total expenditure on EVs wrt baseline

Predicted Impact of EU BEV Subsidies

Production Lines



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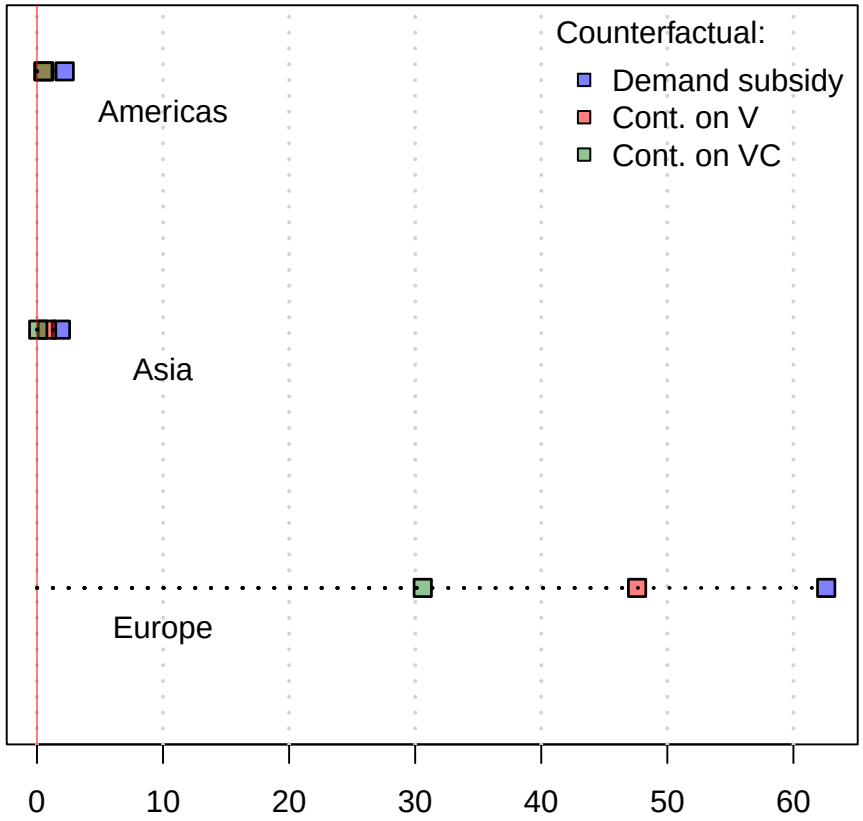


% change total expenditure on EVs wrt baseline

BEV Subsidies: EV Price Changes

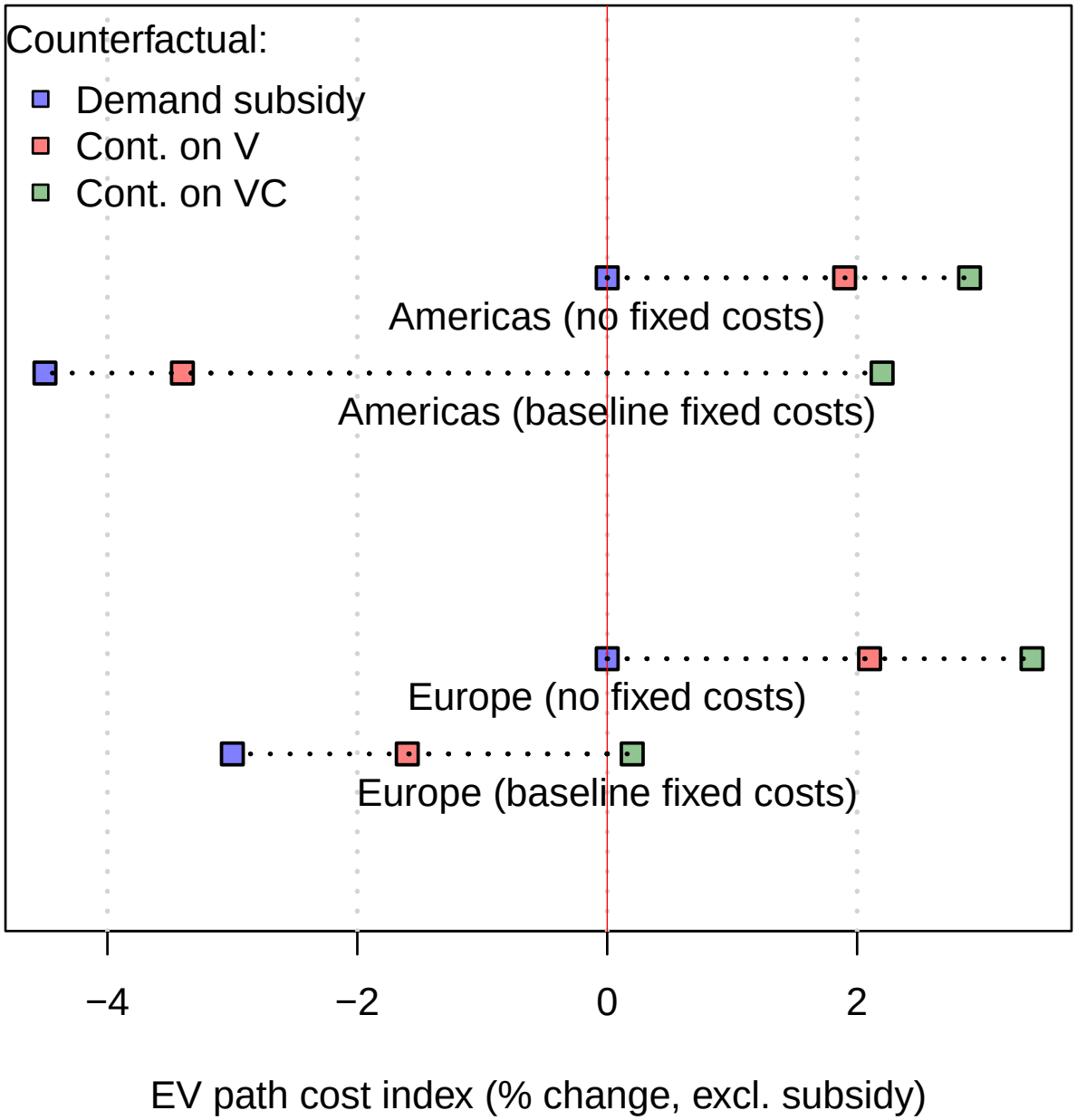
Americas

Policy	Elig. share # path	Elig. share revenue	Cost index subs.	Cost index costs	Tot Exp
1: Unconditional	100.0	100.0	-20.0	-4.5	86.4
2: Continental V	43.4	90.5	-17.4	-3.4	71.1
3: Continental V+C	21.5	68.3	-14.7	2.2	32.3

Europe

Policy	Elig. share # path	Elig. share revenue	Cost index subs.	Cost index costs	Tot Exp
1: Unconditional	100.0	100.0	-20.0	-3.0	62.6
2: Continental V	68.4	85.3	-15.8	-1.6	47.6
3: Continental V+C	47.3	66.8	-12.1	0.2	30.6

Impact of Plant Fixed Costs for Cost Reductions



Part IV

Conclusion

Final Thoughts

- Current trade and industrial policies profoundly affect global production networks
  - ... and have long-lasting consequences for technology sharing and innovation incentives
- In some cases, the policies must weigh competing objectives for domestic production and consumer prices
  - As well as environmental and geopolitical objectives
- But in other cases, the policies have unintended consequences that can set back all of those objectives