MSG-197 Symposium Emerging and Disruptive Modelling and Simulation Technologies to Transform Future Defence Capabilities, 20-21 October 2022, Bath, UK

Enhancing Resilience

Model-based Simulations

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Global Supply Chain (GSC) resilience

"*Over-reliance on the import of key commodities, like energy and exporting advanced technologies, like Artificial Intelligence can create vulnerabilities and weakened resilience.*"

--Secretary General Stoltenberg, 2022

This raises questions:

1. What do we actually know about the Alliance's and Partners' reliance on GSCs?

2. Can we improve the evidence base to avoid excessive foreign dependence and enhance resilience?

What do we know about GSC resilience?

- GSCs are everywhere – 70% of international trade involve exchanges of raw materials, parts and components
- Why? Trade liberalisation, declining transport costs and improving communication technologies allow firms to source their inputs more efficiently; increasing global competition
- GSCs are increasingly complex

- Is this information sufficient to answer the relevant questions?
  - GSC-reliance of our [defence] companies
  - Foreign dependence of our economies in critical sectors

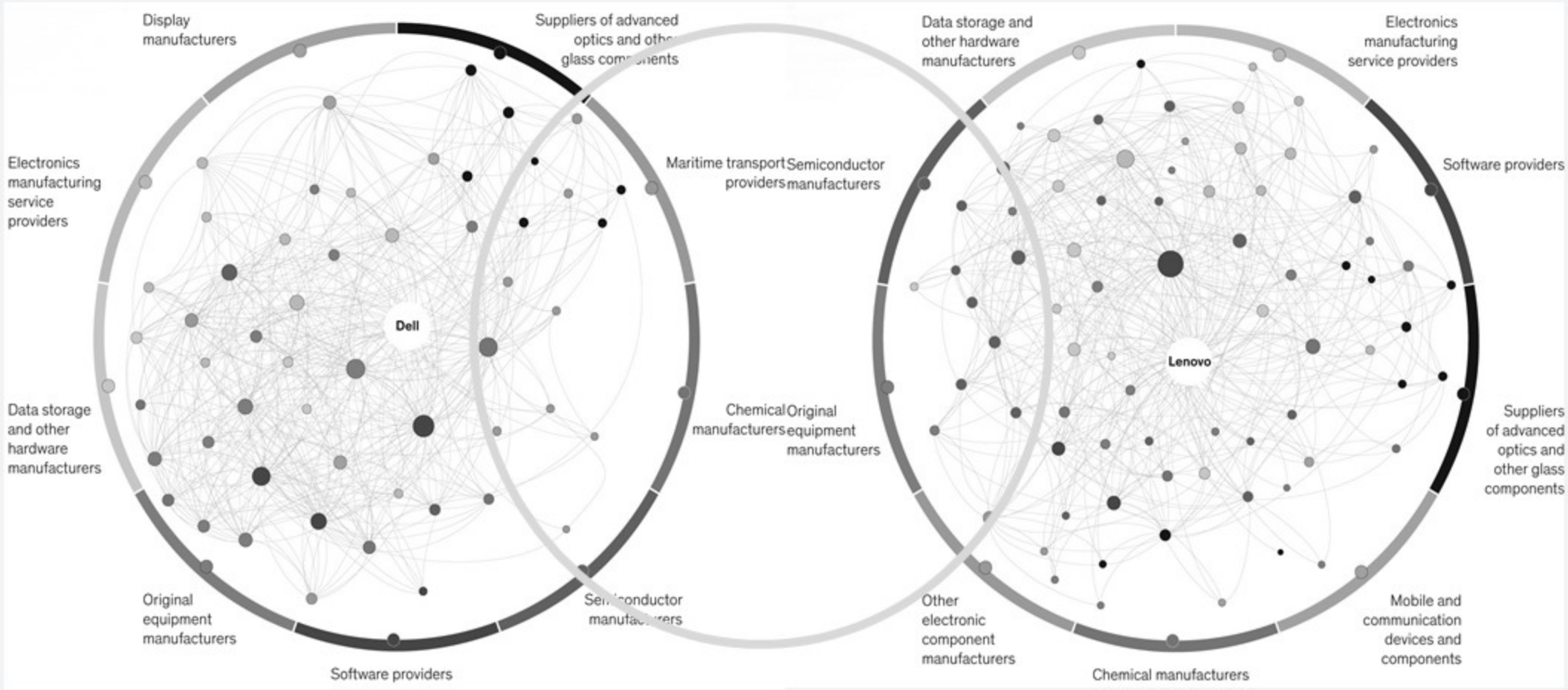
How GSC-reliant are our firms?

Firms have many suppliers of inputs (and input-inputs) and many of them are located abroad

- Airbus [Defence and Space] has 1,676 publicly disclosed tier-one suppliers
- Bloomberg Global Supply Chain Data reveal that Airbus works with >12,000 tier-two suppliers & below globally
- Bloomberg Data show Dell [Military and Defence] has ≈5,000 tier-one and tier-two suppliers worldwide

Because of GSC complexity, firms don't know their own foreign exposure

Dell [Military and Defence] and Airbus [Defence and Space]



Global input interdependencies

- Did defence companies in Russia realise their true GSC dependence before the war?
- Did we realise that Russia's war would affect global supplies of not just food but also the fertilisers that are needed to grow crops around the world?

"To ease the global food crisis, we now must urgently address the global fertilizer market crunch."

--UN Secretary General Guterres, September 2022

How GSC-reliant are our economies?

Share of foreign sources used as intermediate inputs

- Row nations' reliance on inputs from column nation, 2019
- 11.8% of Canada's manufacturing production made using inputs from China
- Global dominance of China in intermediate input trade

(a)	USA	CAN	GER	GBR	FRA	ITA	JPN	CHN	ROW
USA		5.4	1.8	1.0	0.7	0.8	2.1	9.9	13.0
CAN	32.5		2.1	1.5	0.9	0.9	2.0	11.8	21.1
GER	4.6	0.5		3.2	4.7	3.8	1.6	6.9	42.0
GBR	6.2	1.4	6.9		4.1	2.6	1.3	7.7	29.5
FRA	5.6	0.7	10.1	3.8		4.7	1.2	6.4	35.3
ITA	3.5	0.5	8.9	2.6	5.8		0.9	7.6	39.6
JPN	4.1	0.7	1.3	0.7	0.6	0.4		10.7	26.0
CHN	3.7	0.8	1.7	0.6	0.7	0.6	3.2		24.6

Computed based on Foreign Market Reliance (Antras and Chor 2022) methodology and Inter-Country Input-Output (ICIO) Tables http://oe.cd/icio
ROW denotes the Rest of the World

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Share of foreign markets on the sales side

- Row nations' total input sales to column nations' manufacturing industries, 2019
- Canada's sales-side reliance on China is 10.8%
- Global dominance of China in intermediate output trade, also US

(c)	USA	CAN	GER	GBR	FRA	ITA	JPN	CHN	ROW
USA		3.2	1.0	0.8	0.7	0.4	1.3	5.6	9.6
CAN	31.9		0.8	1.3	0.6	0.3	1.7	10.8	9.3
GER	7.1	0.8		3.8	5.1	4.2	1.6	10.0	41.0
GBR	7.0	0.9	4.7		2.9	2.1	1.2	5.5	25.8
FRA	5.2	0.7	8.4	3.9		5.1	1.4	8.0	33.1
ITA	5.9	0.7	6.7	2.6	4.6		1.3	5.4	31.9
JPN	5.7	0.6	1.1	0.6	0.5	0.4		14.4	16.8
CHN	8.0	0.8	1.3	0.9	0.7	0.7	2.8		15.7

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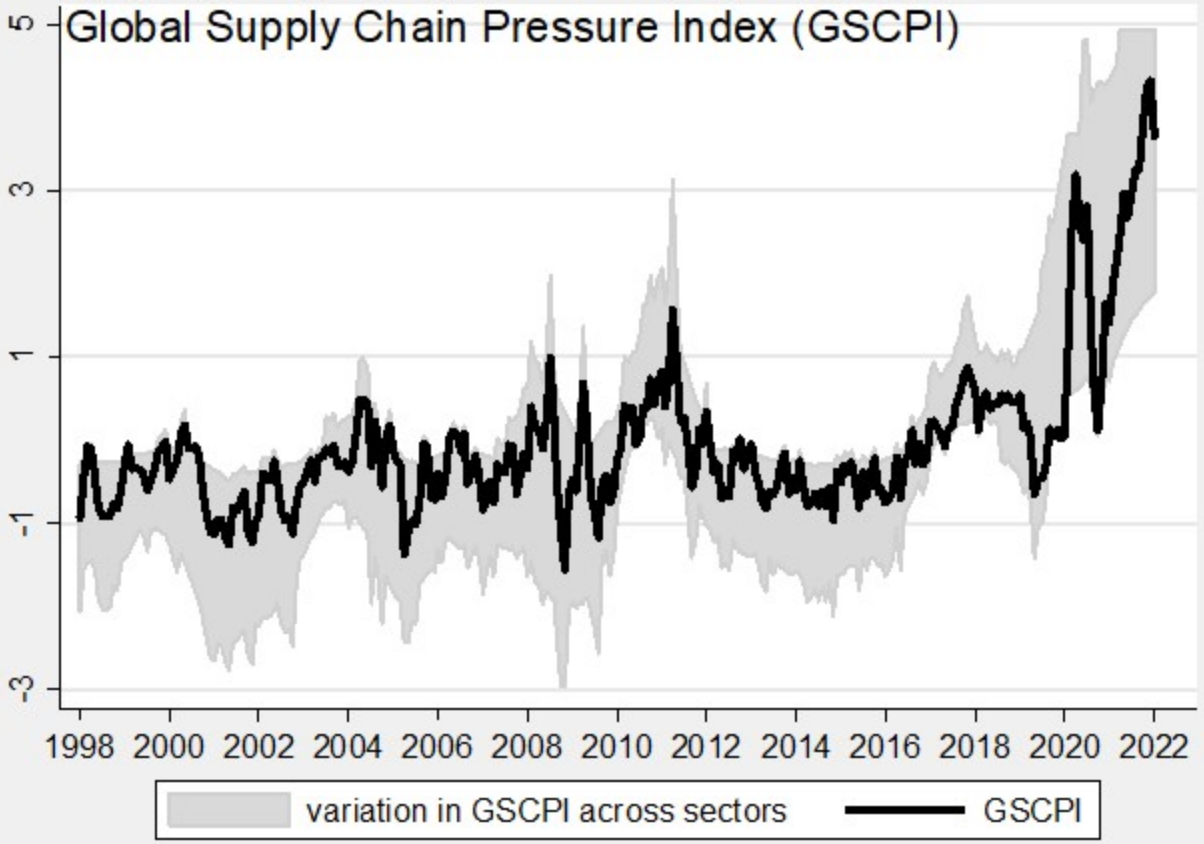
GSC disruptions & vulnerability

GSC pressure at historically high levels since 2020

- Security risks in face of shocks, easier target for hybrid attacks
- Billions of lost income and higher costs
- Challenges increase as supply chains get more complex



Computed based on
www.newyorkfed.org/research/policy/gscpi

Shifting from ex-post to ex-ante

- Suppose we realise that our foreign dependence and GSC vulnerability in critical sectors is higher than we would like to
- What can decision makers undertake to enhance resilience?

Key equation and variables

Shock exposure	×	Vulnerability	=	Value chain uncertainty
				
Unexpected events that cause disruption *Force majeure* Malicious actors Idiosyncratic		Fragility in key areas Demand and inventory Supplier network Transportation and logistics		Risk Ambiguity

To reduce GSC uncertainty, decision makers can:

- Minimise shock exposure
- Reduce vulnerability

Enhancing resilience: Trade-offs

- Resilience can be enhanced by improving GSC transparency, minimising exposure to shocks & building response capacity
- How about trade-offs?

"*we should not trade long-term security needs for short-term economic interests*"

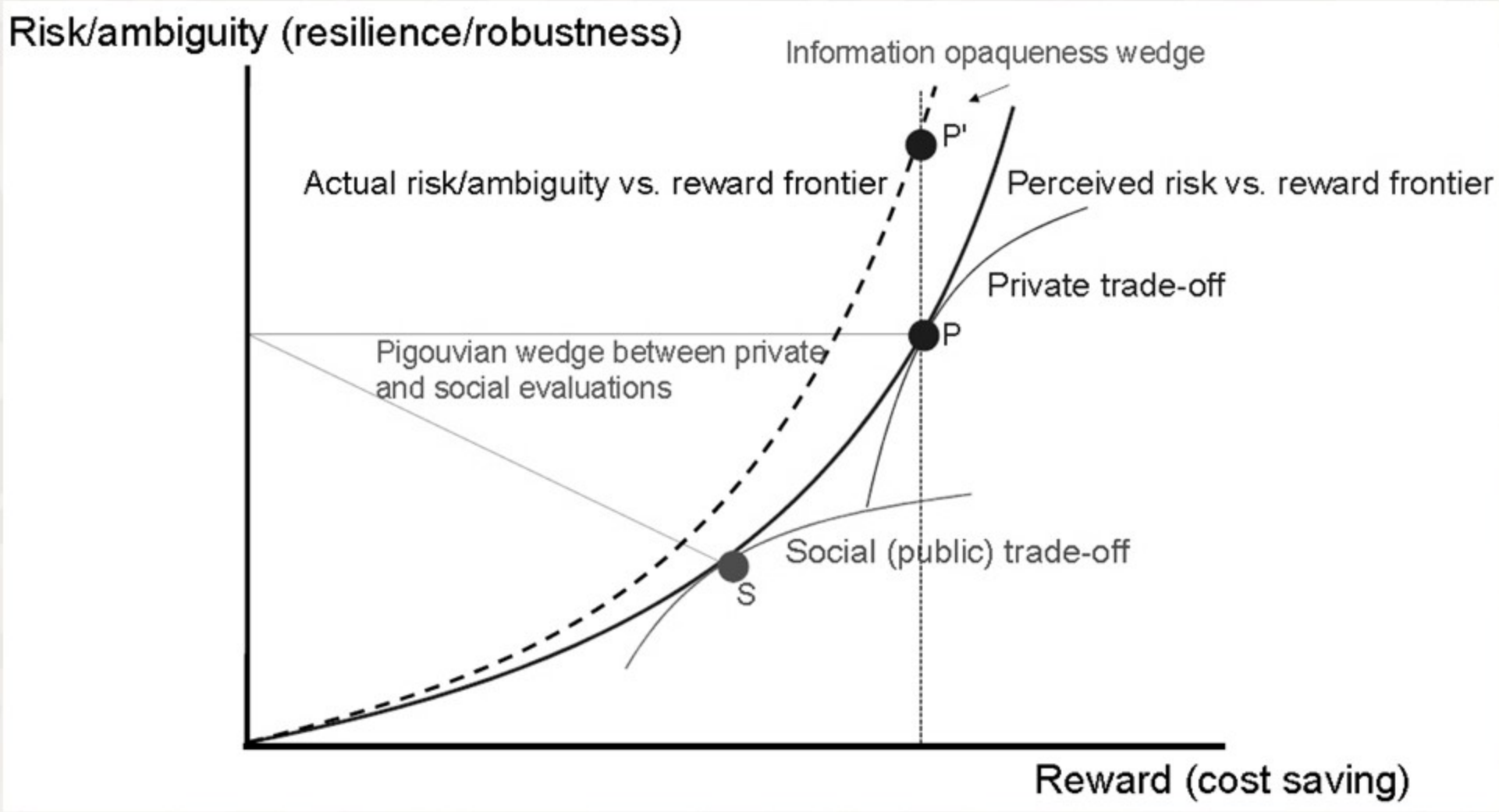
--Secretary General Stoltenberg, 2022

- Robustness / resilience constraint
- Resource mobilisation constraint

Resilience/robustness constraint

- Seven baseline resilience requirements; some with direct GSC relevance
  - Energy supplies: back-up plans and power grids, internally and across borders
  - Food and water supplies safe from disruption or sabotage
  - Communications systems: telecommunications and cyber networks
- Must be maintained even under the most demanding circumstances – design of GSC stress tests and simulation scenarios

Resilience/robustness-efficiency trade-off



Resource mobilisation constraint

В районах Тувы отгружают уголь и доставляют МРС семьям призванных на мобилизацию

вчера, 17:15 Версия для печати

Администрации муниципальных районов приступили к исполнению поручения Главы республики по выделению семьям резервистов первоочередной помощи в виде живых баранов и отгрузке угля. Совместными усилиями власти и активных жителей родные и близкие военнослужащих и они сами должны почувствовать, что не останутся наедине с житейскими проблемами. Именно такую задачу перед республиканскими и муниципальными властями поставил Владислав Ховалыг, создавая центр нию поддержки семьям мобилизованных жителей ики.

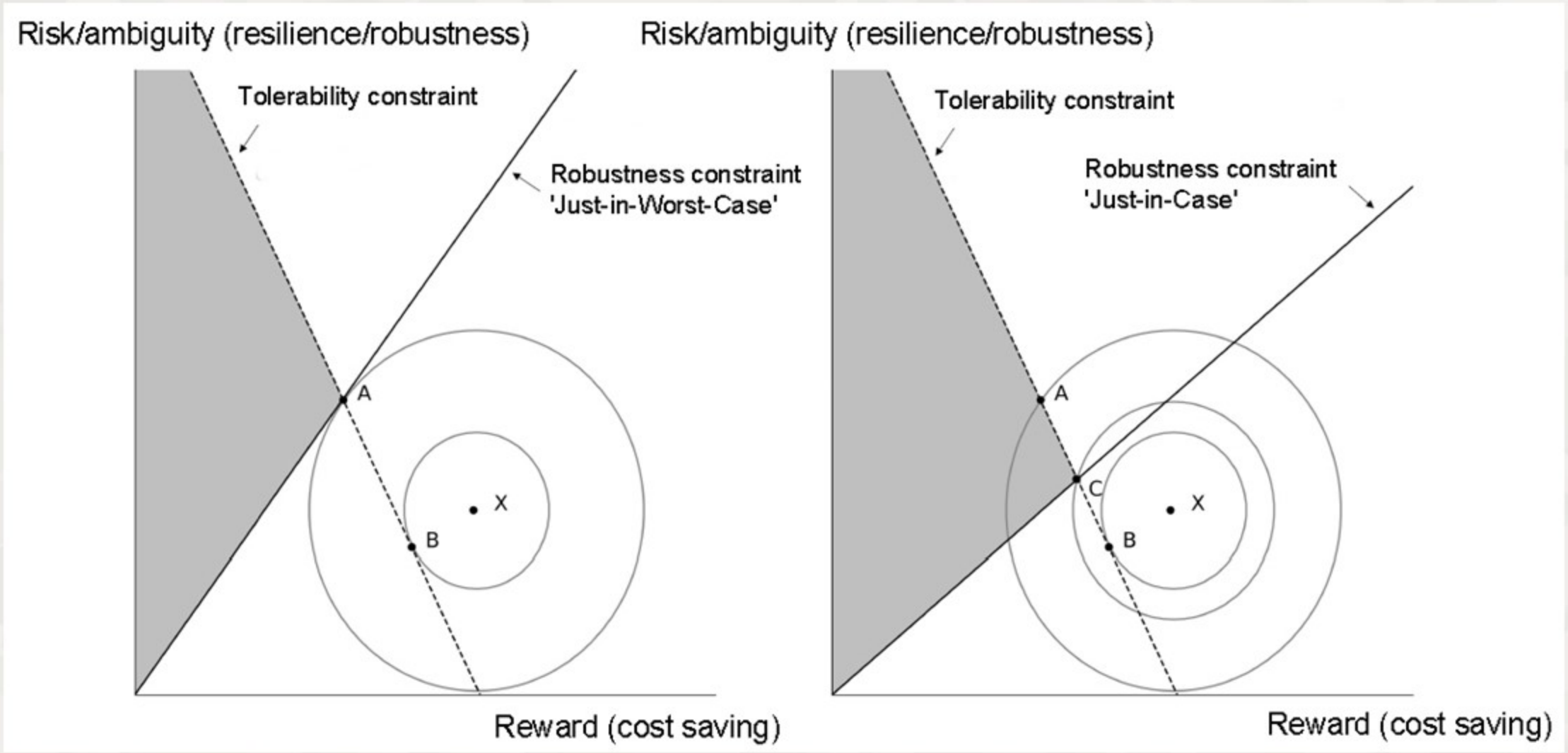
Семьям мобилизованных на Сахалине раздадут по 5 кг рыбы

16:22 4 октября 2022. Наталья Голубкова

Мобилизация, Южно-Сахалинск

Родственников сахалинцев, мобилизованных для участия в СВО, решили поддержать не только экономически и социально-психологически, но и рыбой. Об этом на сегодняшнем брифинге, посвященном оказанию помощи семьям мобилизованных сахалинцев и курильчан, рассказал руководитель регионального исполнительного комитета "Единой России" Михаил Шувалов.

Resource mobilisation constraint



The non-trivial task of decision makers: consider all these factors simultaneously

- Variables decision makers can affect
  - Minimise shock exposure
  - Reduce vulnerability
- Political feasibility constraints
  - Robustness constraint – baseline resilience requirements
  - Resource mobilisation constraint – society's tolerability
- Dimensions that are important
  - Temporal: short-, medium- and long-run
  - Sectoral: critical sectors, uncritical sectors
  - Spatial: geopolitics of trade

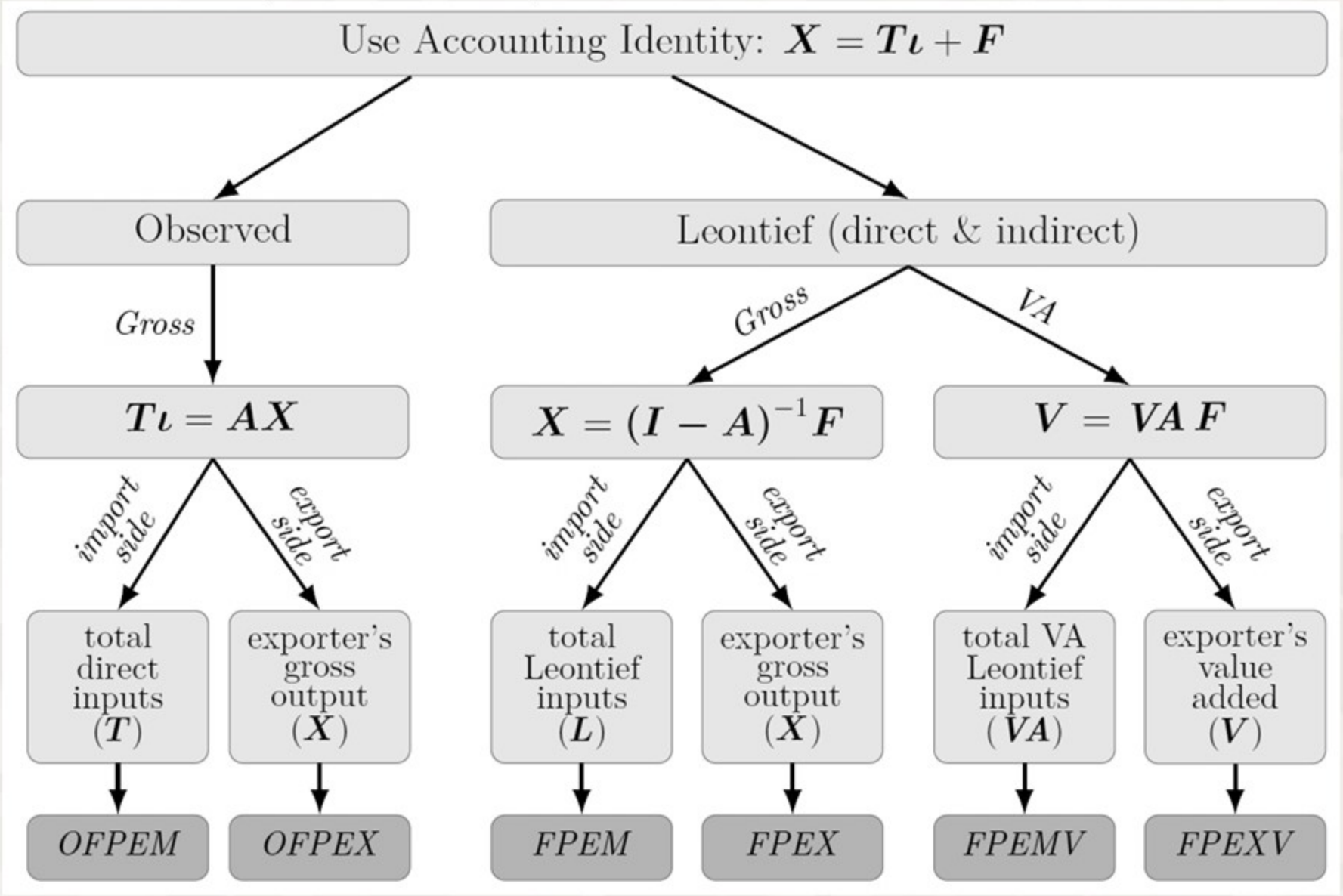
Model-based decision support

- Build a model to support decision makers with evidence base
- The scalable data model has these same three components
- Follows conceptual framework Antras and de Gortari (2020)
  - Intermediate input trade and inter-sectoral linkages
  - Global production takes places in a series of sequential stages
  - Uncertainty increases as manufacturing source inputs from one single (few) cheapest location(s)
  - Diversification of sources reduces risk but at a diminishing rate
- Parameterised with OECD Inter-Country Input-Output tables
- Validating the model

Underlying data framework

		Intermediate use ($\boldsymbol{T}$)				Final demand ($\boldsymbol{F}$)		Gross output ($\boldsymbol{X}$)
		Nation A		Nation B		Nation A	Nation B	
		Sector 1	Sector 2	Sector 1	Sector 2			
Nation A	Sector 1	T_{1A1A}	T_{1A2A}	T_{1A1B}	T_{1A2B}	F_{1AA}	F_{1AB}	X_{1A}
	Sector 2	T_{2A1A}	T_{2A2A}	T_{2A1B}	T_{2A2B}	F_{2AA}	F_{2AB}	X_{2A}
Nation B	Sector 1	T_{1B1A}	T_{1B2A}	T_{1B1B}	T_{1B2B}	F_{1BA}	F_{1BB}	X_{1B}
	Sector 2	T_{2B1A}	T_{2B2A}	T_{2B1B}	T_{2B2B}	F_{2BA}	F_{2BB}	X_{2B}
Value Added ($\boldsymbol{V}$)		V_{1A}	V_{2A}	V_{1B}	V_{2B}			
Gross output ($\boldsymbol{X}$)		X_{1A}	X_{2A}	X_{1B}	X_{2B}			

GSC and input-output flows in the model



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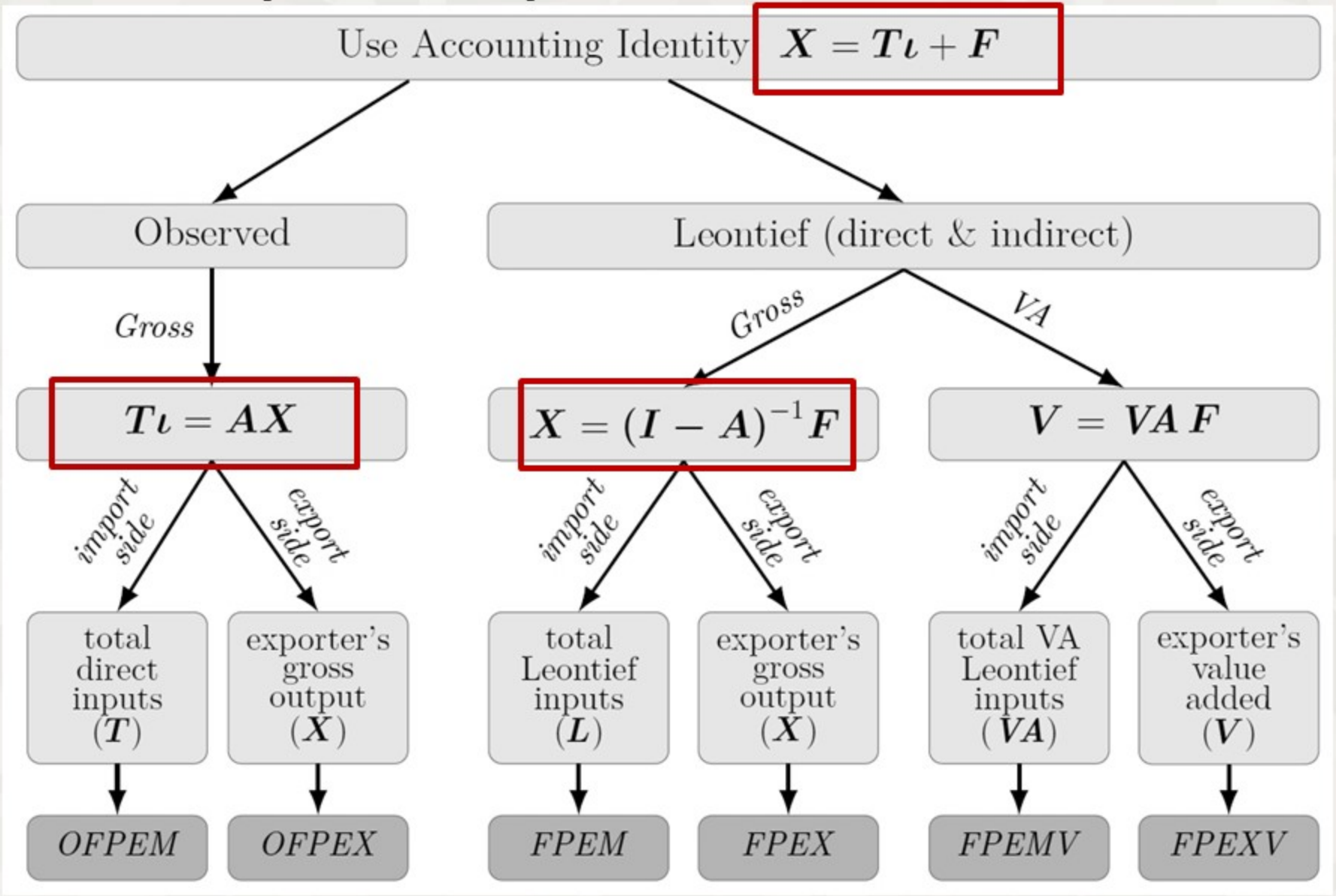


Example: Airbus [Defence and Space]

- A product rolls off the assembly line in Stevenage, UK
  - We can say Airbus was made in Stevenage
  - First-level truth (X), but it is not the whole truth
- Stevenage plant buys inputs from other sectors located at home and abroad
  - Trace the first-level production location of inputs
  - Airbus has 1,676 publicly disclosed tier-one suppliers (T)
- Entire recursive sequence of all the inputs into all the inputs
  - Third-level answer - the whole truth of foreign input reliance (LF)
  - Airbus works with >12,000 tier-two suppliers & below worldwide

Structural model fit and validation

- While the mechanisms captured by our micro-founded model seem plausible, the calibrated model involves a number of assumption
- Consider multiple approaches to validate the model
  - Structural model fit – moments: data vs. model
  - Out-of-sample validation: our micro-founded model of firm behavior matches reduced form evidence from Bloomberg GSC survey data
  - Model peer-review
- Work in progress!

Model-based simulations

- First, simulate hypothetical shocks and perform stress-tests
- Second, simulate alternative policy choices in what-if-analysis
- Sensitivity analyses and uncertainty analyses of simulation results

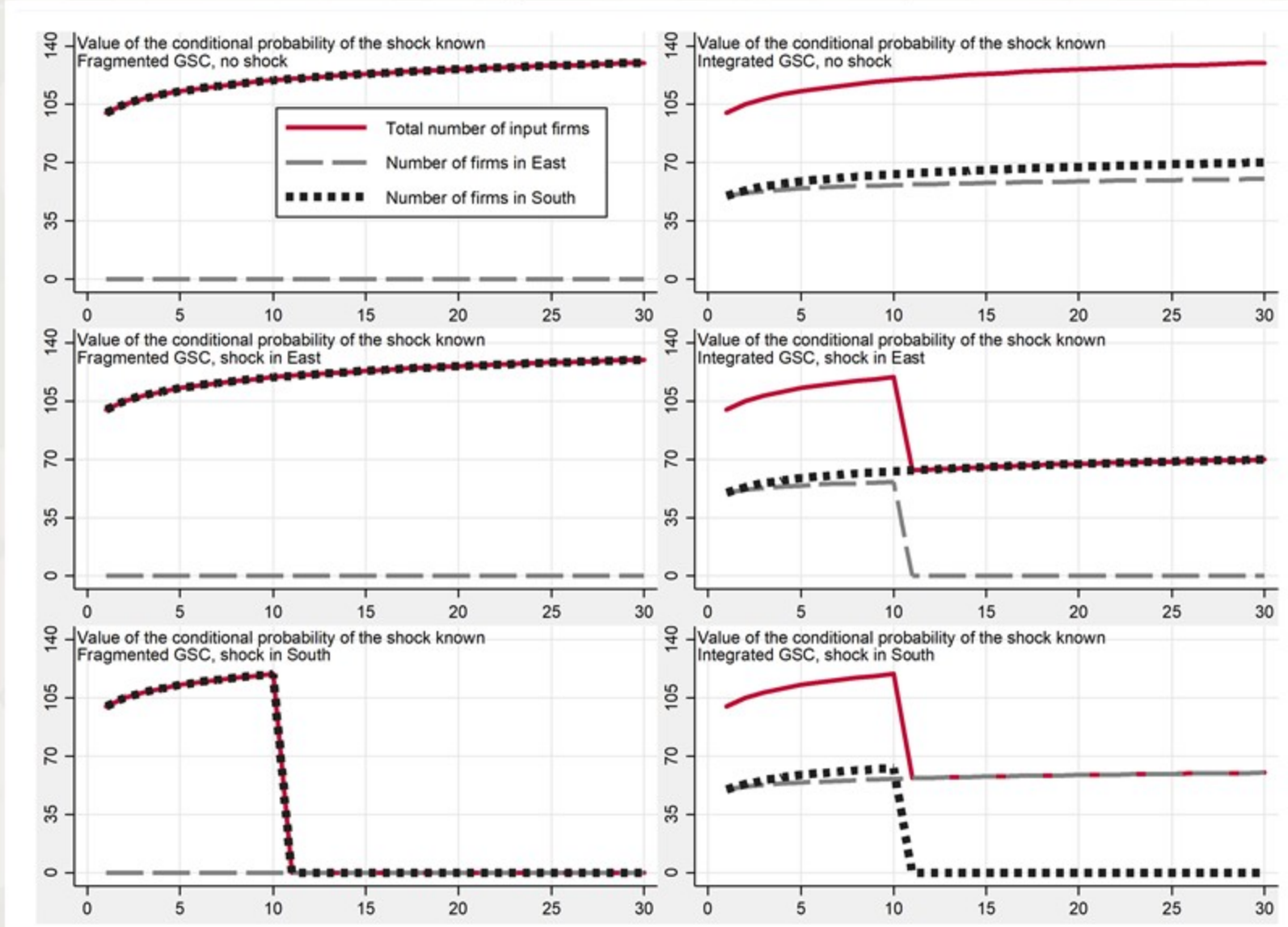
Shocks & stress-tests

	No aggregate shock	Aggregate shock in East	Aggregate shock South
Fragmented risk-free scenario	Externality, known probability, no shock realised	Externality, known probability, shock realised in East	Externality, known probability, shock realised in South
Fragmented GSC risk scenario	Externality, known shock distribution no shock realised	Externality, known shock distribution shock realised in East	Externality, known shock distribution shock realised in South
Fragmented GSC ambiguity scenario	Externality, unknown distribution, no shock realised	Externality, unknown distribution, shock realised in East	Externality, unknown distribution, shock realised in South
Integrated risk-free scenario	Internalised externality, known probability, no shock realised	Internalised externality, known probability, shock realised in East	Internalised externality, known probability, shock realised in South
Integrated GSC risk scenario	Internalised externality, known shock distribution no shock realised	Internalised externality, known shock distribution shock realised in East	Internalised externality, known shock distribution shock realised in South
Integrated GSC ambiguity scenario	Internalised externality, unknown distribution, no shock realised	Internalised externality, unknown distribution, shock realised in East	Internalised externality, unknown distribution, shock realised in South

Following a shock to model parameters, compute the counterfactual value of key equilibrium variables

GSC shocks & model impulse-response

- Simulation results with known value of the conditional shock probability
- Y-axis the number of intermediate input firms; X-axis time periods
- Fragmented GSC - left panels;
- Integrated GSC - right panels



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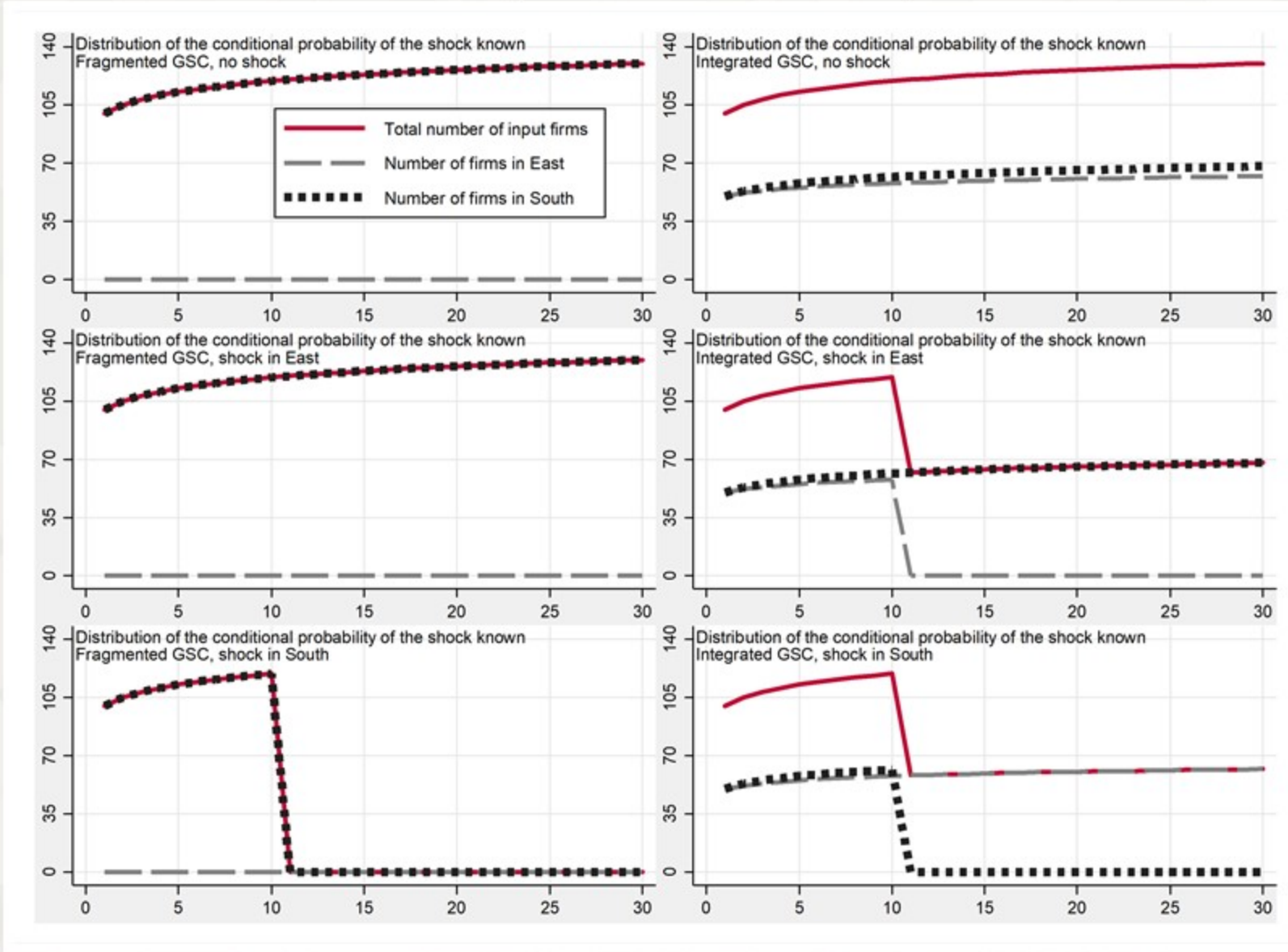

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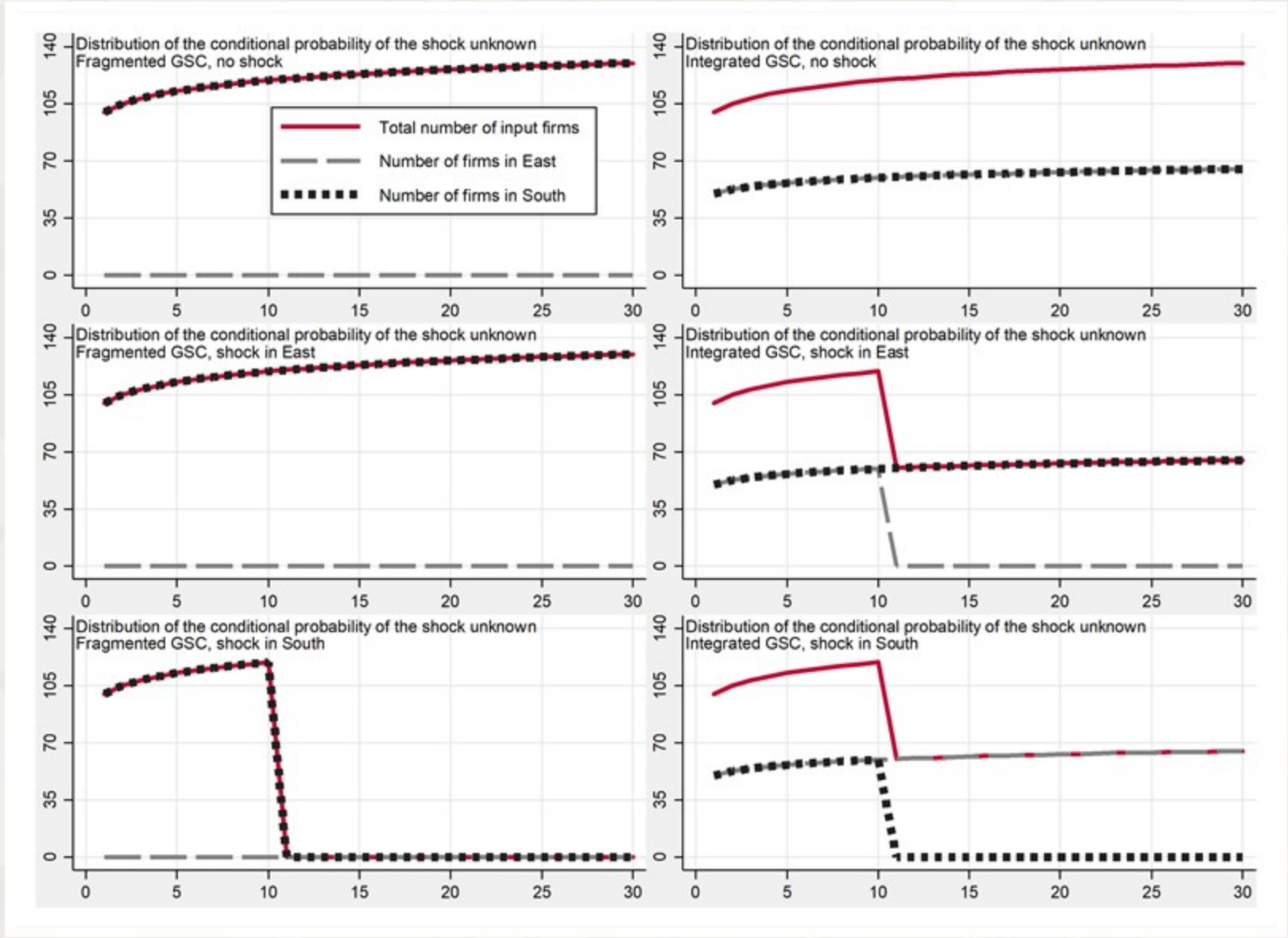


Counterfactual simulations: main results

Optimal firm response	Baseline, no shock expectations (S0)	Demanding circumstances (S1) Scenario	Most demanding circumstances (S2) Scenario
efficiency-robustness trade-off	maximise efficiency	maximise efficiency under risk	maximise efficiency under ambiguity
robust decision rule	inefficiency aversion: the stock at firm held to a minimum	risk aversion: amount of inventory that maximises profit	ambiguity aversion: maximise payoff in the worst-case
source diversification cost	zero/ zero	medium/ medium	all the time/ high
firm strategy	'Just-in-Time'	'Just-in-Case'	'Just-in-Worst-Case'

GSC robustness and resilience increases from S0-S1-S2 at the expense of efficiency loss

Rationale for resilience-enhancing policies

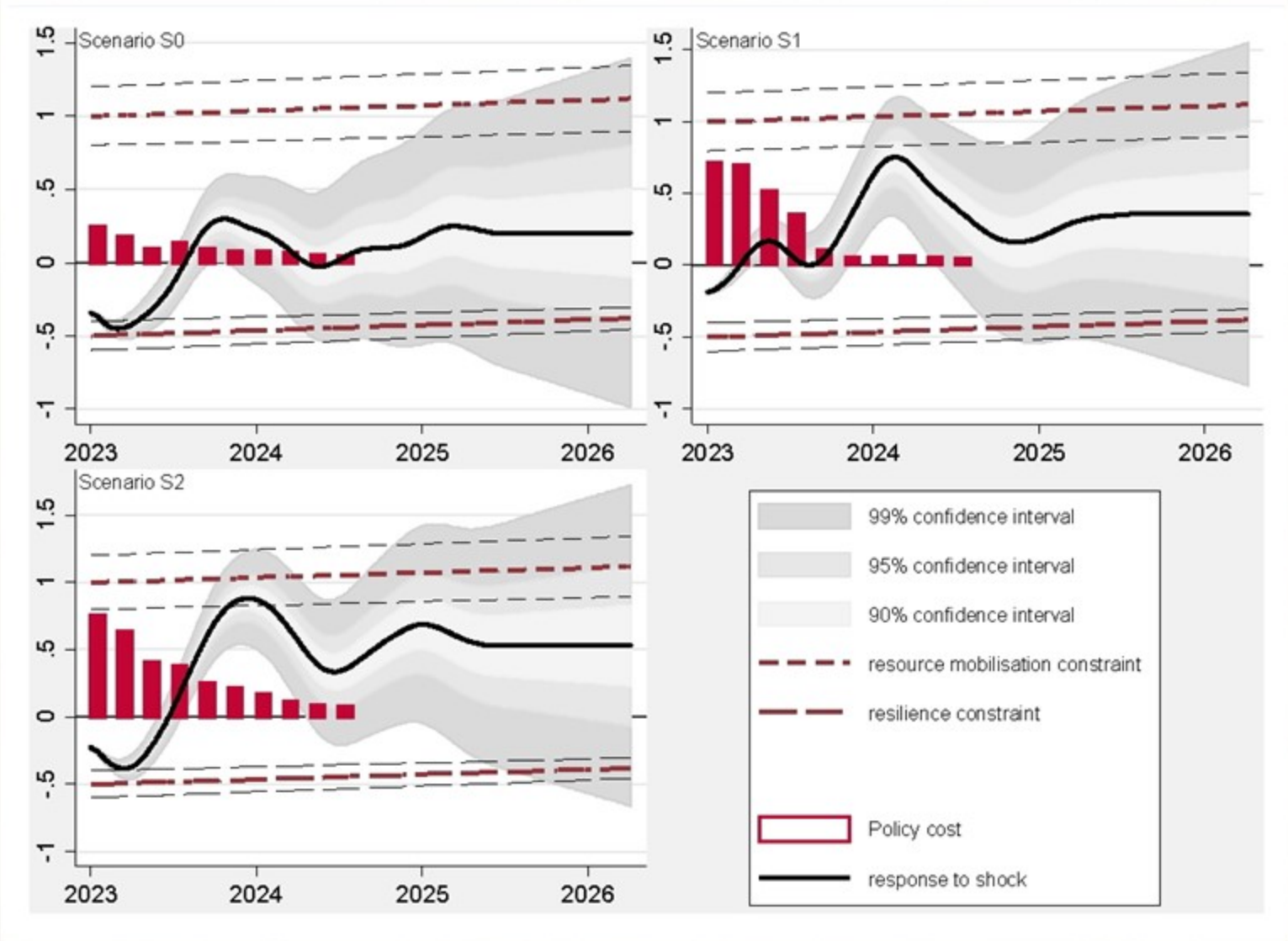
- Externalities: wedge between private & social evaluations
  - Private sector firms prefer more risk for any given level of reward
  - Social evaluation of the risk-reward trade-off usually put a greater stress on the risk than private evaluation
- Market imperfections: GSC complexity, intransparency
  - Companies do not know all the suppliers of their suppliers, GSC participants know rarely the whole truth of their foreign exposure
  - Private misjudgments as to how fragile GSCs actually are may lead to a misperception of the true vulnerability
- Increasing (mis)use of foreign supply dependence as hybrid threats by adversaries

Pro-resilience policy options

- Pro-active policy can counteract the depreciating vulnerability
- One policy approach is to provide information and/or subsidies to increase voluntary investments in resilience
  - Minimum information on suppliers (and the suppliers of suppliers), including possibly assessment of inventories for critical inputs
  - Align private incentives by providing a subsidy: e.g. in 2020, Japan set up a fund to compensate firms that diversify out of China
- A more controversial but increasingly common policy alternative is to mandate investments in GSC-resilience
  - Mandatory standards ensure a wider adoption of robust sourcing
  - Mitigate GSC risks and ambiguity in presence of hybrid threats

Model-based policy support

- Simulate policies of compensating input sourcing from cost-disadvantaged locations in what-if-analysis
- Shock exposure and pro-resilience policy-diversification subsidy
- Policy costs & policy feasibility constraints constrain response set in the model



Summing up

- The decision making by considering all the relevant socio-politico-economic factors simultaneously is a non-trivial task
- Both the ex-post and ex-ante evidence base for decision makers to enhance resilience can be improved
- Model-based evidence can support decision makers in identifying relevant, effective and efficient strategies
- Sensitivity analyses and uncertainty analyses provide credible ranges of likely impacts of decision maker choices

Related work at NATO

- Aggregated Resilience Model of the STO's Modelling and Simulation

  Simulate Political, Military, Economic, Social, Information and Infrastructure shocks (e.g. electricity blackout, cyber-attack, martial law enforcement, big human movement, state of war, armed conflict)
- Resilience Data Analytics Tool of the ACT's Innovation Hub
- Multi-Dimensional Data Farming
- Causal Reasoning

Selected references and data sources

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Thank you for attention!

Any questions?

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Sectors: 45 industries ISIC Rev.4

Code	Industry
D01T02	Agriculture, hunting, forestry
D03	Fishing and aquaculture
D05T06	Mining and quarrying, energy producing products
D07T08	Mining and quarrying, non-energy producing products
D09	Mining support service activities
D10T12	Food products, beverages and tobacco
D13T15	Textiles, textile products, leather and footwear
D16	Wood and products of wood and cork
D17T18	Paper products and printing
D19	Coke and refined petroleum products
D20	Chemical and chemical products
D21	Pharmaceuticals, medicinal chemical and botanical products
D22	Rubber and plastics products
D23	Other non-metallic mineral products
D24	Basic metals
D25	Fabricated metal products
D26	Computer, electronic and optical equipment
D27	Electrical equipment
D28	Machinery and equipment, nec
D29	Motor vehicles, trailers and semi-trailers
D30	Other transport equipment
D31T33	Manufacturing nec; repair and installation of machinery and equipment

Code	Industry
D35	Electricity, gas, steam and air conditioning supply
D36T39	Water supply; sewerage, waste management and remediation activities
D41T43	Construction
D45T47	Wholesale and retail trade; repair of motor vehicles
D49	Land transport and transport via pipelines
D50	Water transport
D51	Air transport
D52	Warehousing and support activities for transportation
D53	Postal and courier activities
D55T56	Accommodation and food service activities
D58T60	Publishing, audiovisual and broadcasting activities
D61	Telecommunications
D62T63	IT and other information services
D64T66	Financial and insurance activities
D68	Real estate activities
D69T75	Professional, scientific and technical activities
D77T82	Administrative and support services
D84	Public administration and defence; compulsory social security
D85	Education
D86T88	Human health and social work activities
D90T93	Arts, entertainment and recreation
D94T96	Other service activities
D97T98	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use

12 of 45 industries provide inputs to the manufacture of weapons and ammunition

- "Other Manufacturing" includes the highly defence dependent "Scientific Instruments" industry
- "Other Transport Equipment" consists primarily of aerospace and shipbuilding
- "Other Chemical Products" is a critical supplier of the explosive materials used in ammunition and other weaponry
- "Medicinal and Pharmaceutical Preparations" industry provides medical supplies as well as chemical and biological weapons
- "Office and Accounting Machinery" consists of the computer industry
- "Radio, Television, and Communication Equipment" contains both the electronics and communications industries that are critical to high technology weaponry
- "Furniture and Fixtures of Metal" supplies metal fixtures for boats, planes, and other vehicles
- "Other chemical and petroleum products" industry supplies military vehicles with refinery products