Simulating and evaluating the bullwhip effect along an end-to-end semiconductor automotive supply chain amid COVID-19 crisis

Anylogic Conference 2021

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Infineon Technologies AG
Date: September 2021

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Bumpy road ahead for semiconductor supply chain to recover from COVID19 – chip shortage hits global OEMs and might last longer

BUSINESS

Computer chip shortage disrupts global car production

The auto industry has been left scrambling for semiconductors as a swift recovery catches their suppliers off guard. Strong demand for iPhones, Galaxy tabs and Playstation consoles from housebound consumers is to blame.

Chip Shortage Reaches Smartphone Makers

Shipments are slowing and prices are rising as companies hunt for parts; supply-chain wait times enter the danger zone

Global chip shortage puts car supply chain under the microscope

Severe shortage of crucial supplies risks becoming recurring crisis for auto industry

very of chip supplies © FT montage; Bloomberg

Chip shortage will last beyond 2022 as demand far outstrips supply, Intel chief says

Head of largest chipmaker in U.S. says short-term fixes may help, but building additional factories will take years

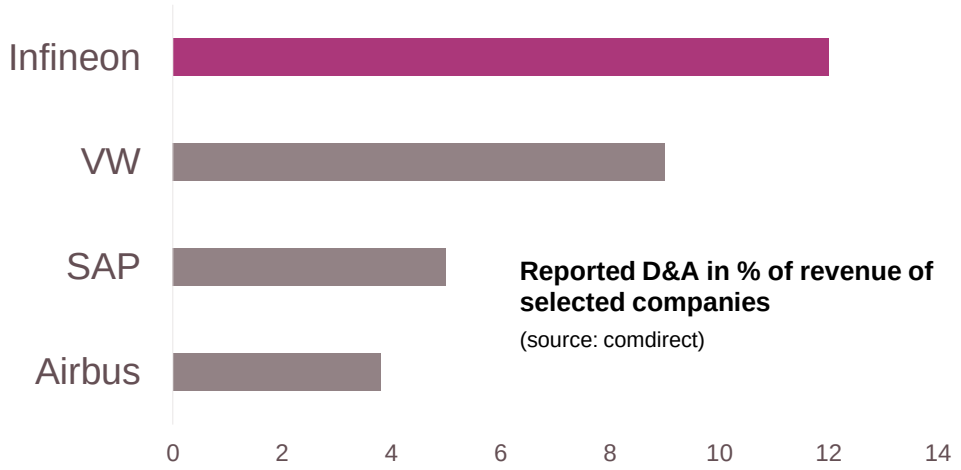
- During the crisis automotive demand dropped significantly which resulted in inventory overshoot (people worked from home therefore they commuted less ..etc.)
- Few months later demand overshoot happened and the chip shortage occurred

Sources: DW, Bloomberg, Tagesschau, Financial times, Neue Züricher Zeitung

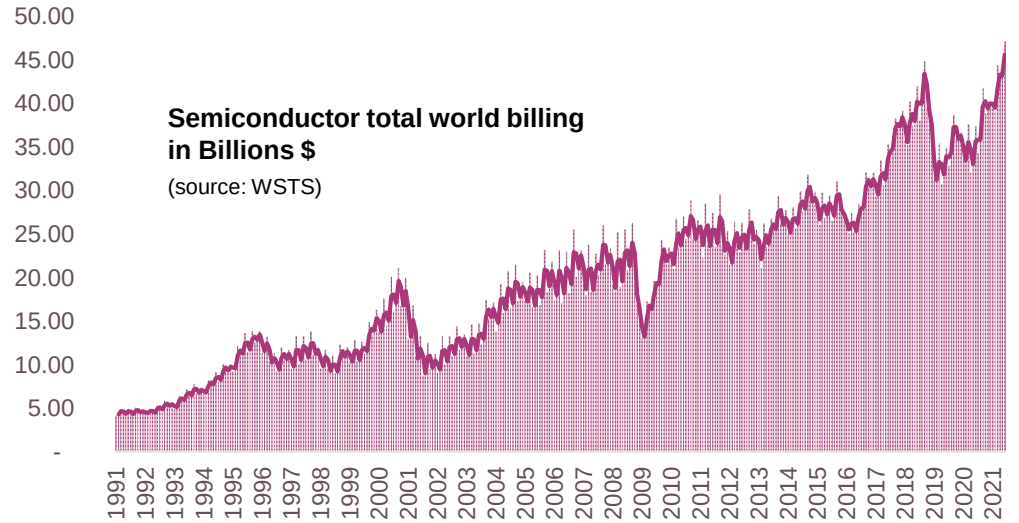
The semiconductor industry is characterized by capital intensity & high demand volatility

Characteristics of the semiconductor industry

Semiconductor manufacturing is highly capital intense



Semiconductor demand is difficult to forecast – also before COVID

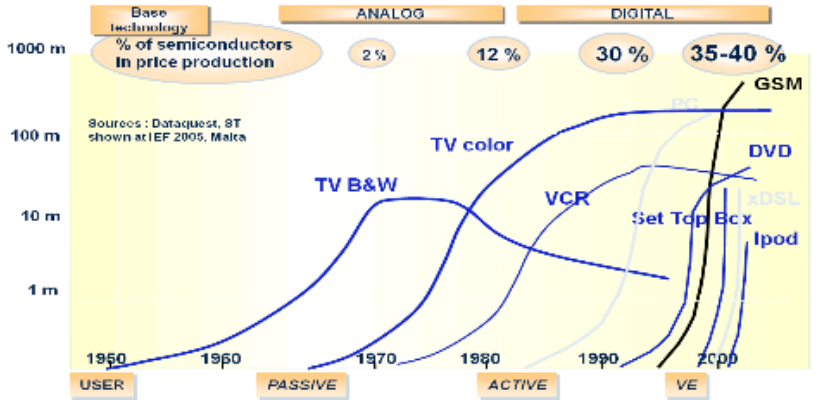


- 24*7 operations due to capital cost and technical reasons
- Capacity lead times of one year or more due to special machines

- Dynamic markets
- Rapid innovation cycles
- Bullwhip effect

The semiconductor industry is challenged by steep ramp, short lifecycle & long cycle time

Fast changing demands vs. fixed boundaries



Source: Dataquest, ST
shown at IEF 2005, Malta

- Steep product ramp-ups/-downs
- Short product life cycles

- Long cycle times (e.g. 6 months)
- Positioned early in the value chain

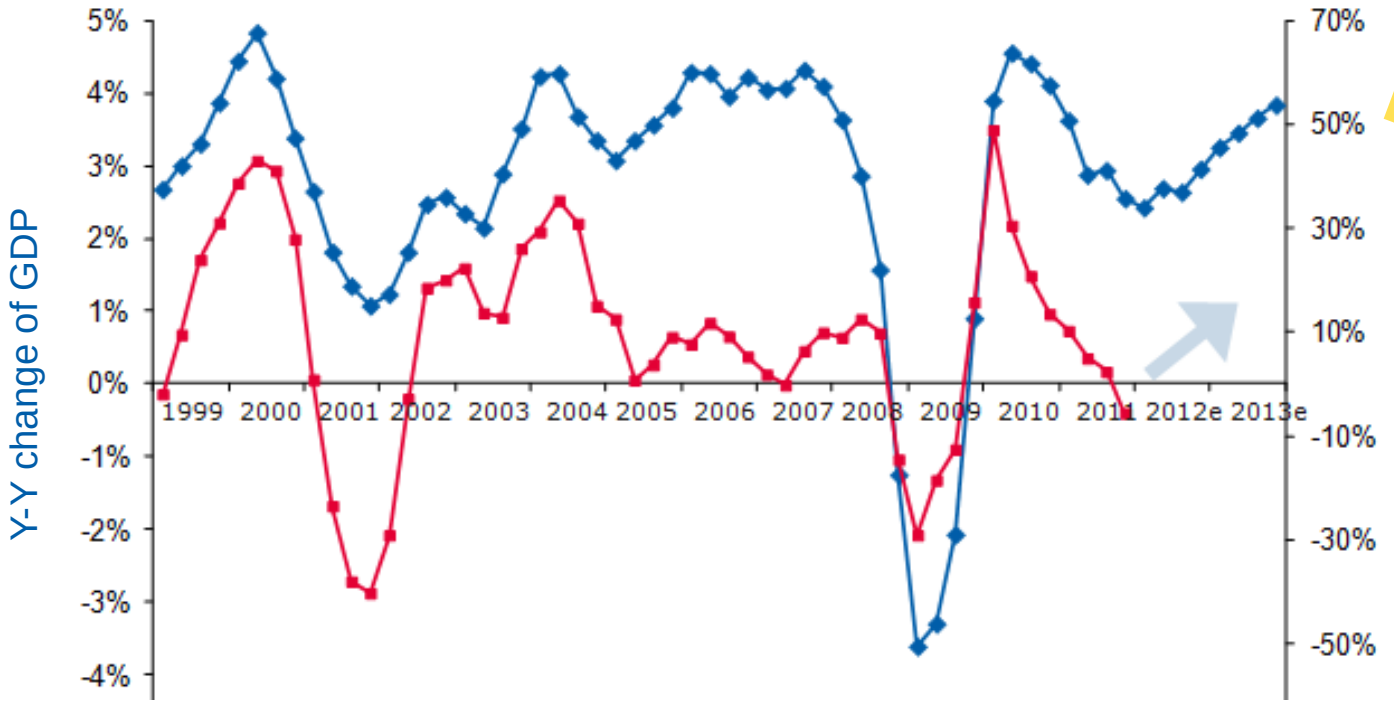
Hans Ehm presented the bullwhip effect back in 2012, about its existence in the semiconductor supply chain

Recap from Anylogic Conference 2012

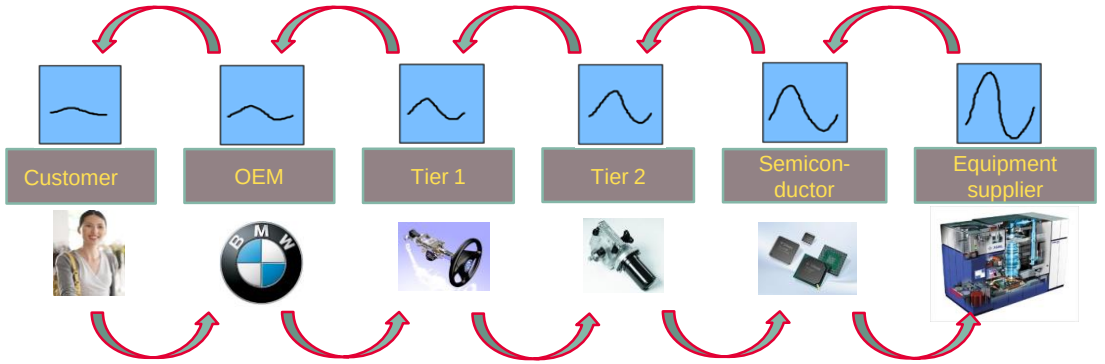
The Bullwhip Effect

Anylogic Conference Dec 13 2012
Hans Ehm Supply Chain Innovation

The real risk comes from the nonaligned supply chains - the bullwhip effect



Recap from Anylogic Conference 2012



Bullwhip Effect

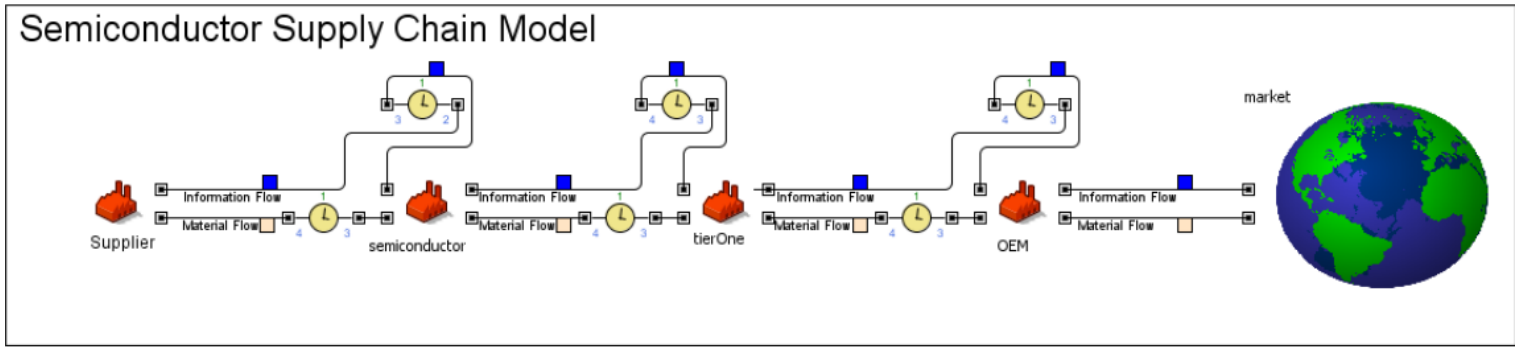
Overshooting in the value chain

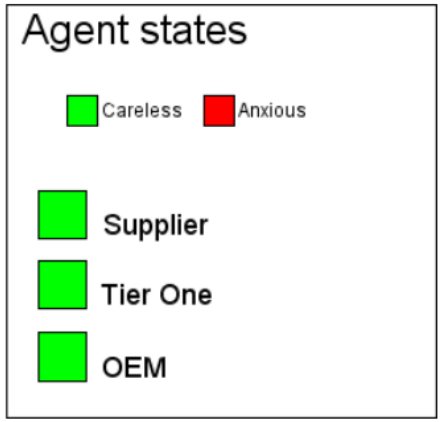
We used discrete-event simulation in combination with agent-based modelling to represents the interactions

Recap from Anylogic Conference 2012

Model description (General)

- Main view in Anylogic®:



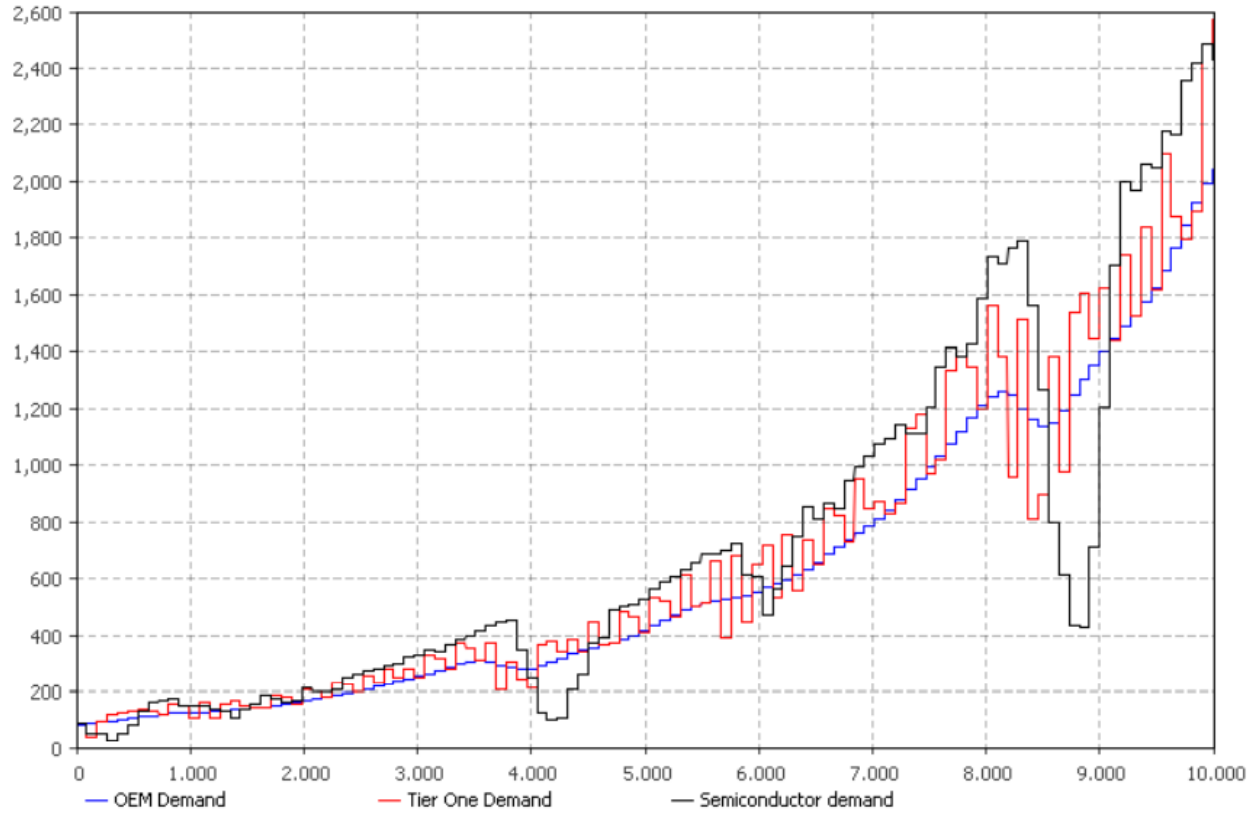


We used discrete-event simulation in combination with agent-based modelling to represents the interactions

Results show that the bullwhip effect can be seen (2)

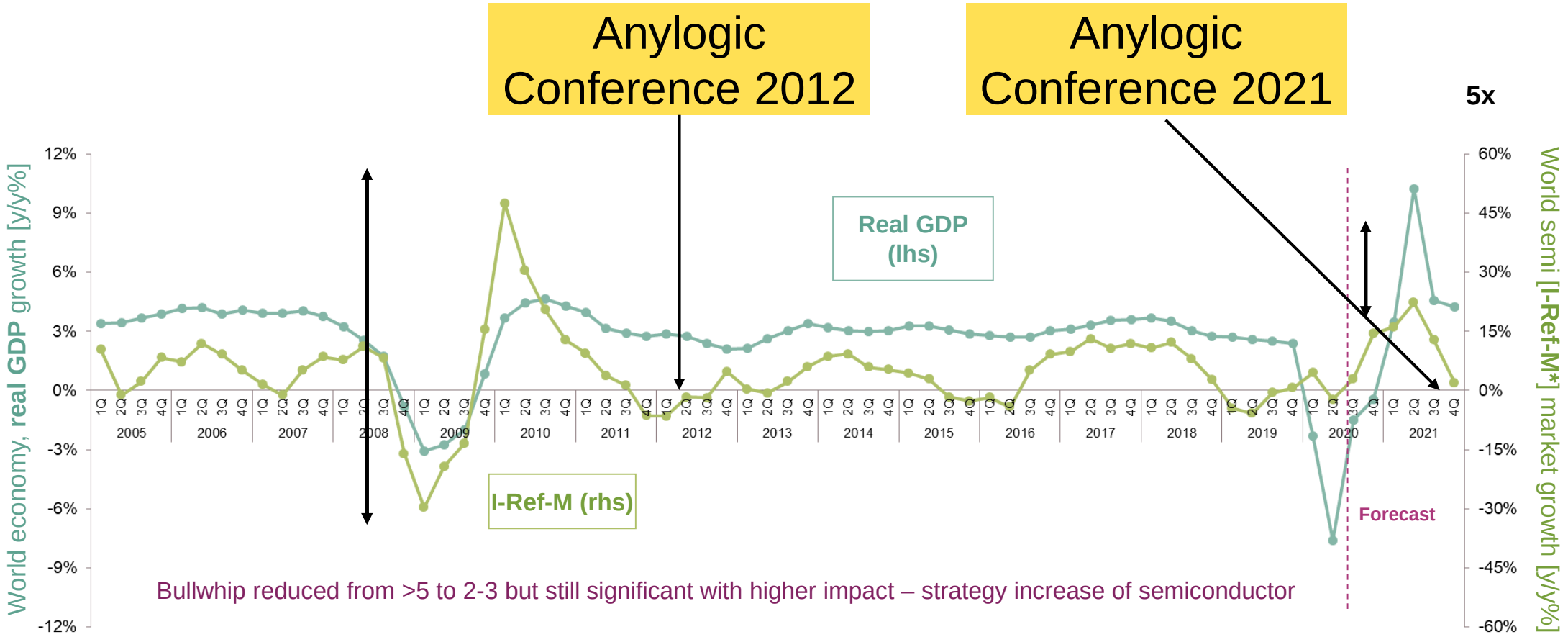
Recap from Anylogic Conference 2012

- Resulting demand fluctuations:



Global Demand

In 2020 semiconductor market growth de-coupled from crash caused by COVID; Reducing the bullwhip has a high potential → but how?



Bullwhip reduced from >5 to 2-3 but still significant with higher impact – strategy increase of semiconductor

*I-Ref-M = Infineon Reference Market = Total semiconductor US-Dollar based **market revenues** excl. DRAM, NAND Flash, MPU. – Real GDP = Inflation adjusted (real) Gross Domestic Product of all countries of the world; total of local values converted with in each case current US-$ exchange rates. World real GDP is from chain-weighted index. Quarterly data (year-over-year growth rates)
Sources: WSTS Bluebook for Historical Data, 30 November 2020 & Forecast Update, November 2020; based on or includes content supplied by IHS Markit Economics & Country Risk, Comparative World Overview Tables, 17 November 2020
Specific disclaimer for Omdia and IHS Markit data: Information is not an endorsement of Infineon Technologies AG. Any reliance on these results is at the third party's own risk

End-to-end (E2E) system dynamics simulation

Desire

- Simulate **demand recovery** from COVID-19 in the automotive semiconductor supply chain
- Understand **impact of bullwhip effects** for different end-market recovery scenarios
- Provide a **tool for evaluation** of collaboration efforts and habits

Action

- **Determine** end-market demand recovery scenarios
- **Build** system dynamics simulation in AnyLogic 8
- **Fit** model parameters using historical data
- **Perform** sensitivity analysis

Outcome

- Better **understanding** of relationship between **demand recovery** scenarios and the **bullwhip effect**
- Prediction of **incoming demand signal** to **semiconductor** depending on respective end-market demand scenario

Acknowledgement: This study was supported by Maximilian Jaenichen as part of his master thesis in collaboration with the automotive division of Infineon

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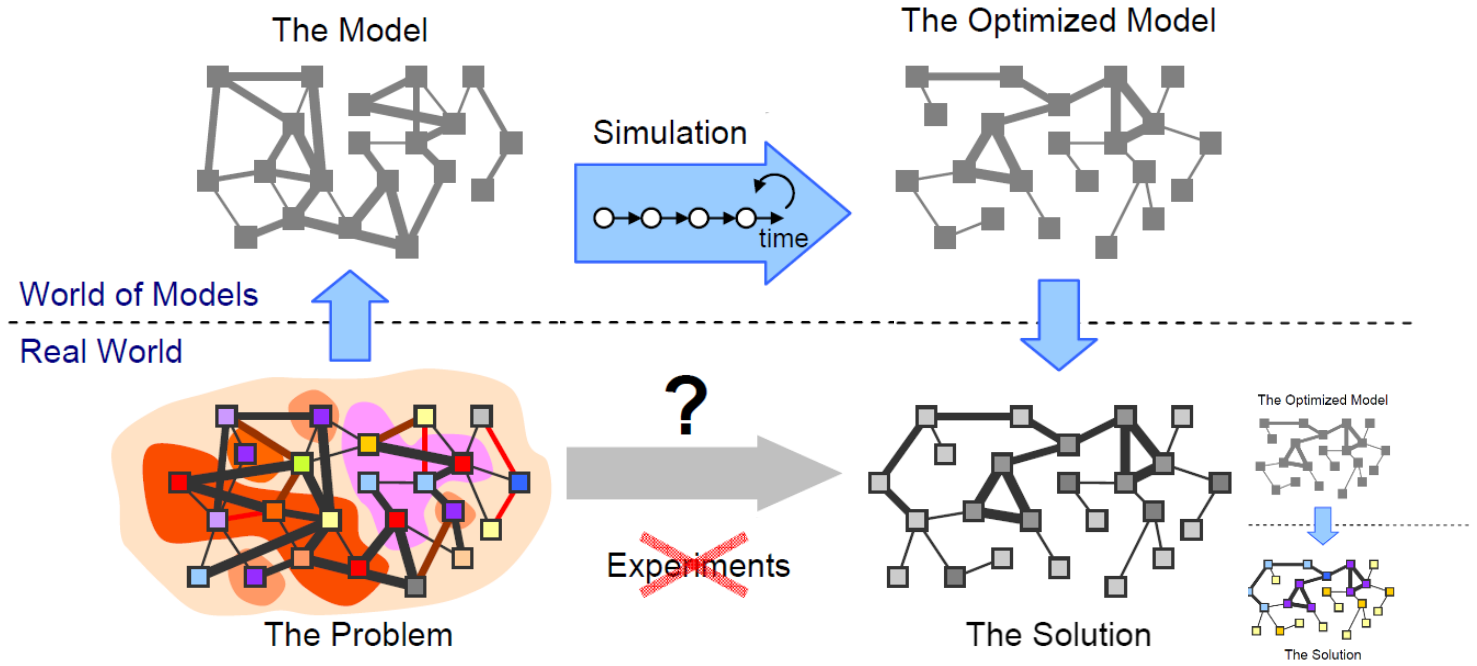
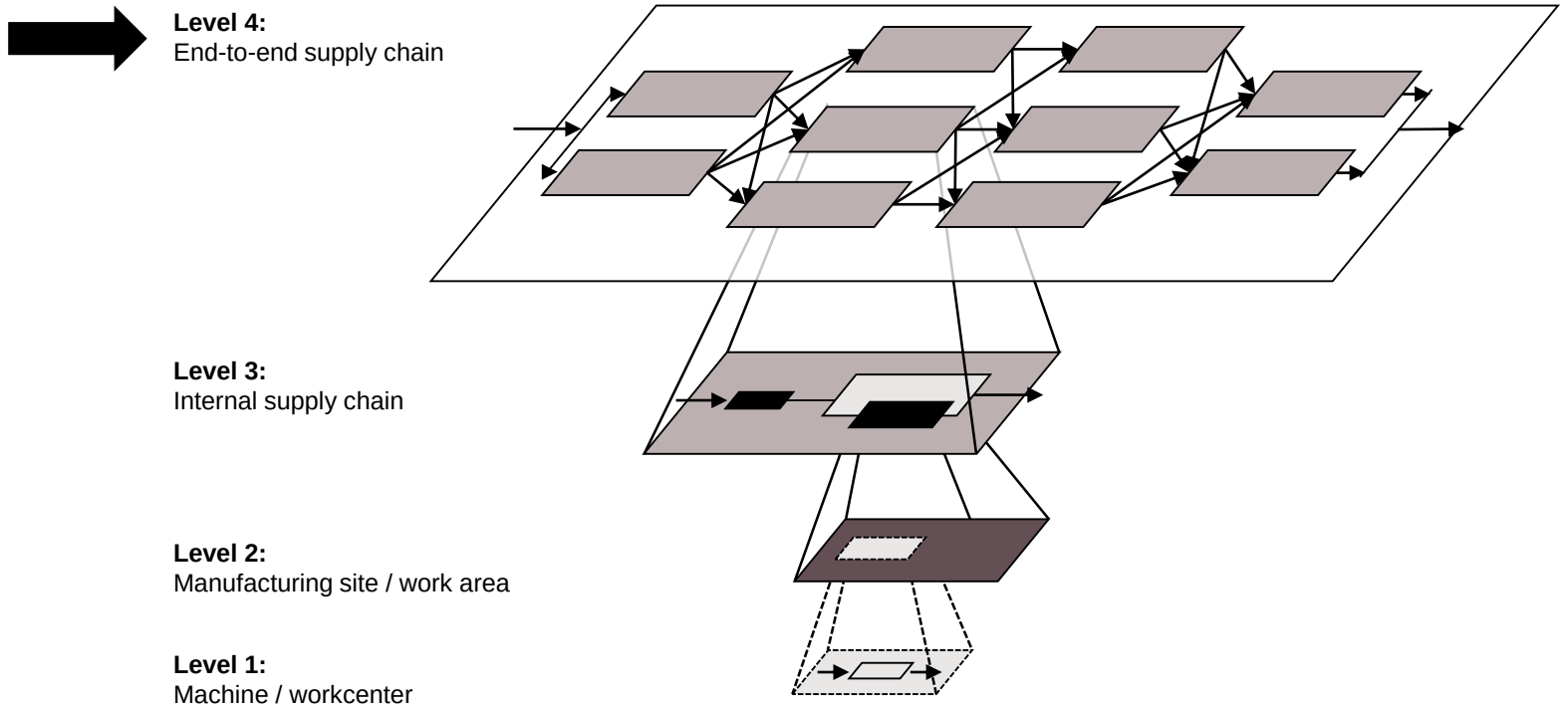
Why Simulation?



- Complex system, complex set of problems
- Costly to experiment on Real system
- Risk free world, we can run several simulations
- Optimal solution to be implemented in real system

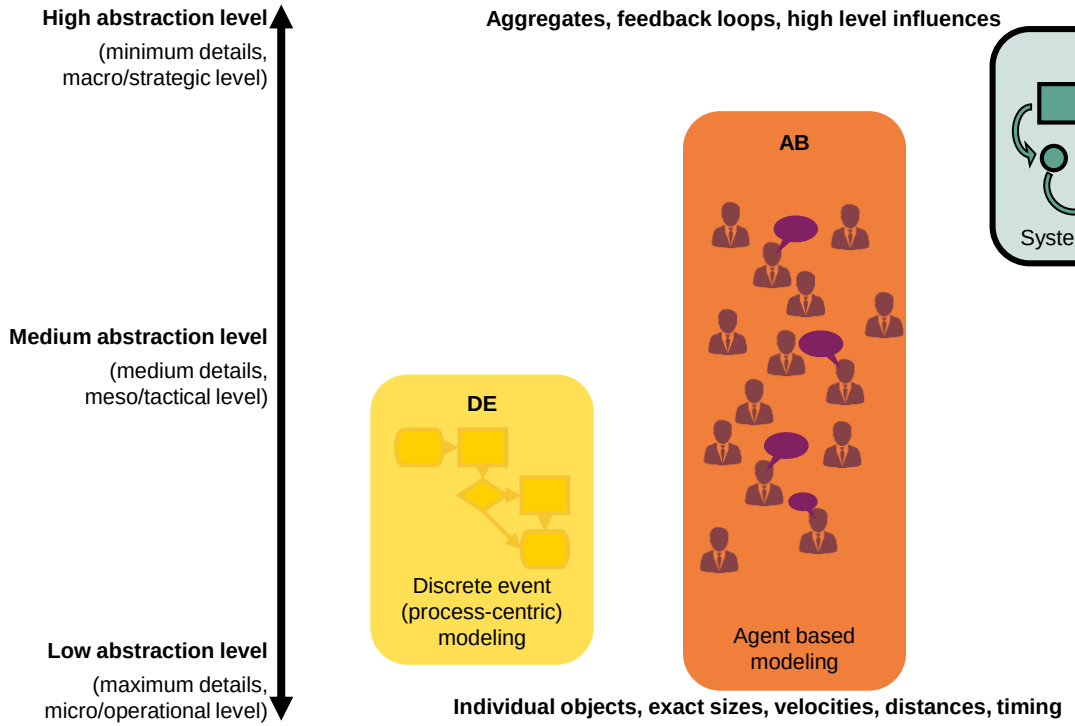
We use anylogic®

Framework for supply chain simulation in the semiconductor industry



Sources: Yagi, Ponsignon (2014), Fowler et al. (2015)

Several simulation techniques are available – and supported in AnyLogic 8



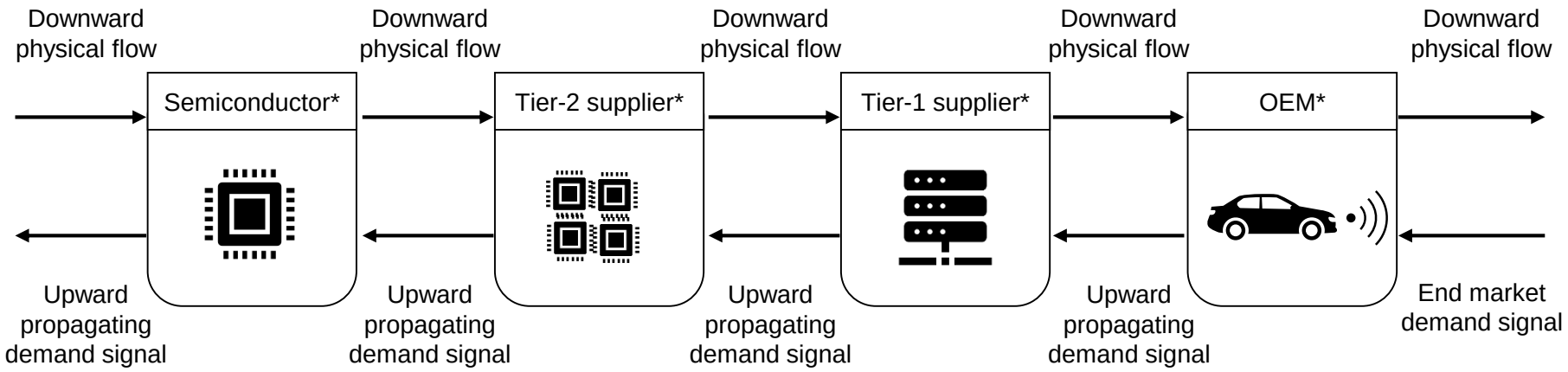
System dynamics simulation:

- System thinking
- Feedback loops
- Interrelationships between components

(See Sterman (2000) for more information)

Sources: Grigoryev (2018)

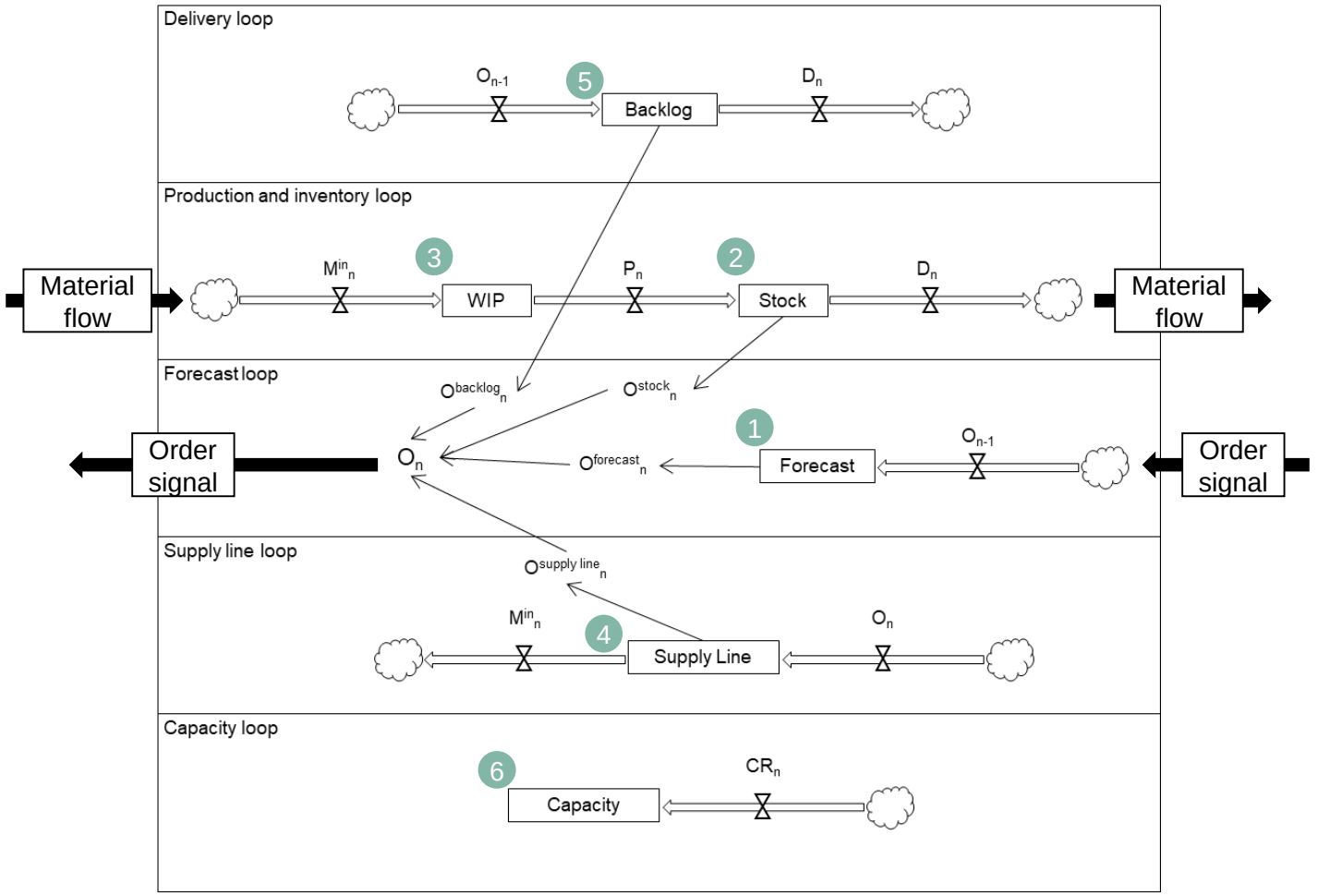
End-to-end supply chain setup considers OEMs, Tier-1 suppliers, and semi manufacturers – on a globally aggregated level



- **Information flow** propagates upstream, while the **physical flow** of products propagates downstream the supply chain.
- **Four echelons** are specifically modelled in the simulation. Each echelon handles the input with several control loops to foward the output to the next stage. Different echelons have different parameters for the same components**.
- The supply for the semiconductor echelon is guaranteed by the silicon supplier. For the scope of this model, supply to the semiconductor assumed to be infinite.

*behavior of each echelon is driven by system dynamics approach (s. next slide)
** including forecasting, capacity, work-in-process, stock, backlog and supply line management

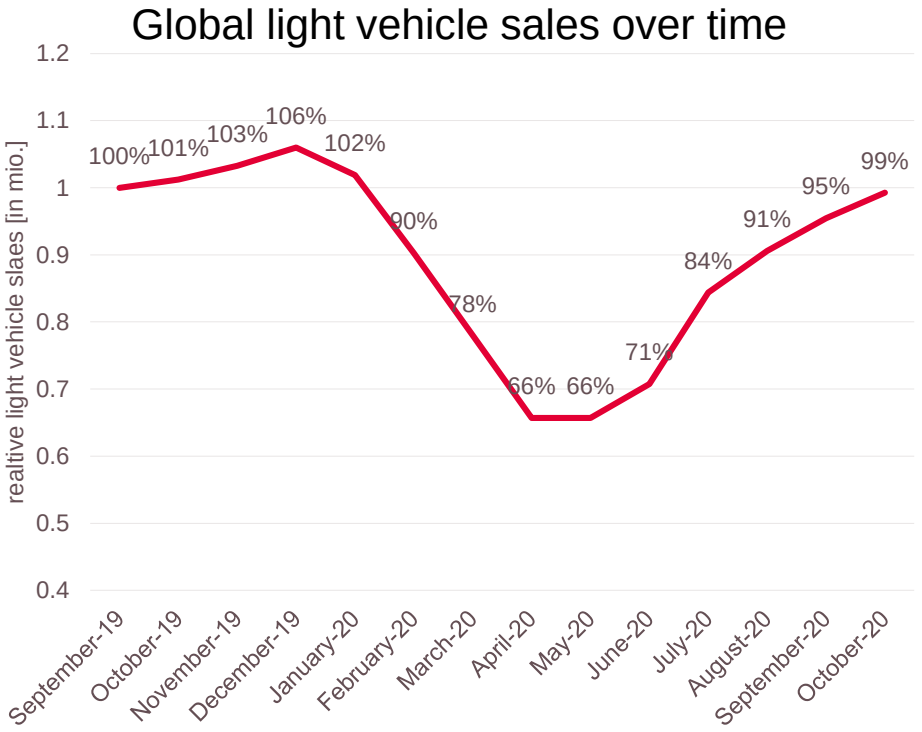
Underlying system dynamics structure for each echelon – Leveraging Anylogic multimethod modelling

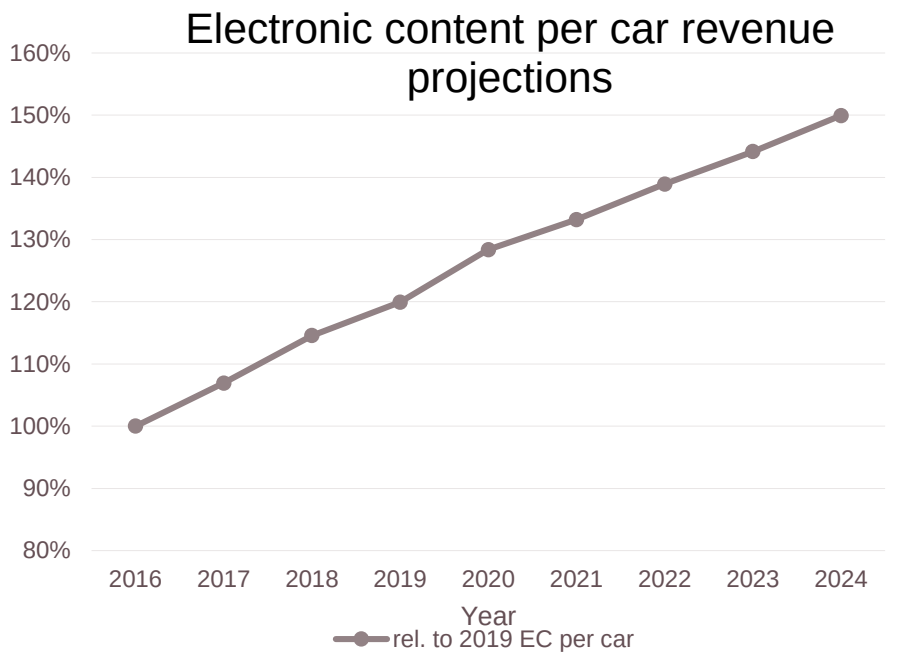


Considered components:

1. Forecasting to anticipate future production
2. Stock to track current inventory levels
3. Work-in-process to track production levels
4. Supply line incoming material and orders
5. Backlog to track order fulfillment
6. Capacity to track loading and utilization

Light vehicle sales faced harsh drop during crisis while electric content per car is expected to grow in the near future





- Historical data reveals **harsh drop of >30%** in global light vehicle sales as a consequence of the pandemic

- ***Growth* of ~4-7% p.a.** in electric content of per car will drive sales for automotive semiconductor industry as well

Source: internal market analysis, IHS Markit report

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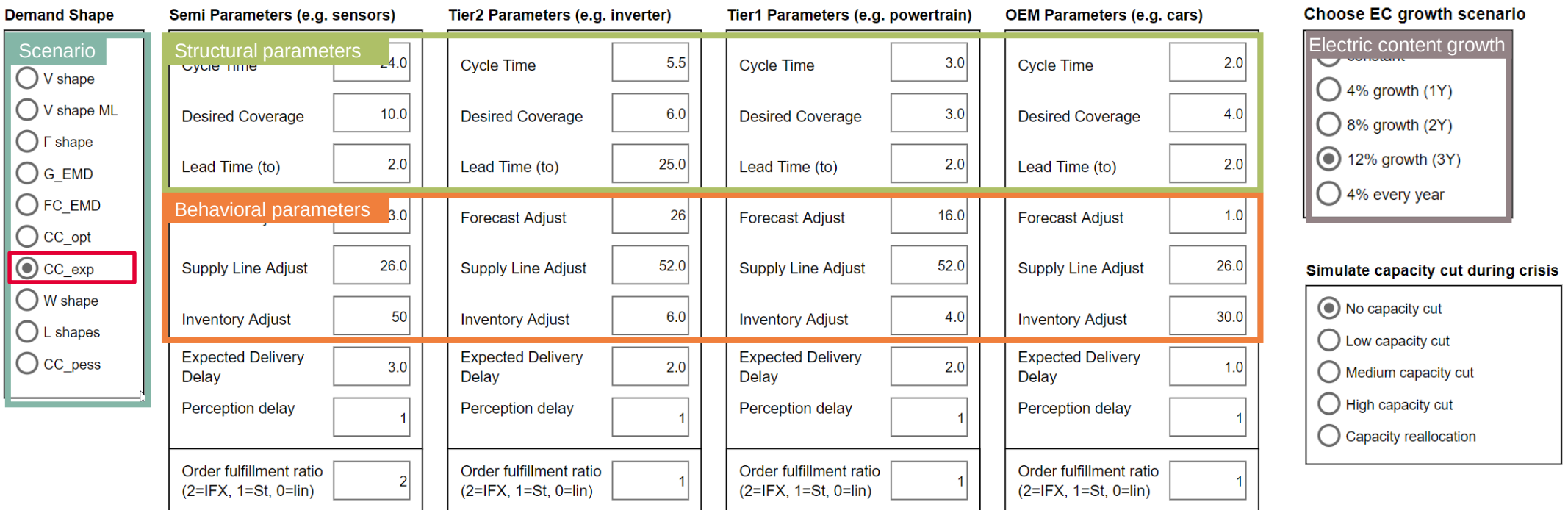
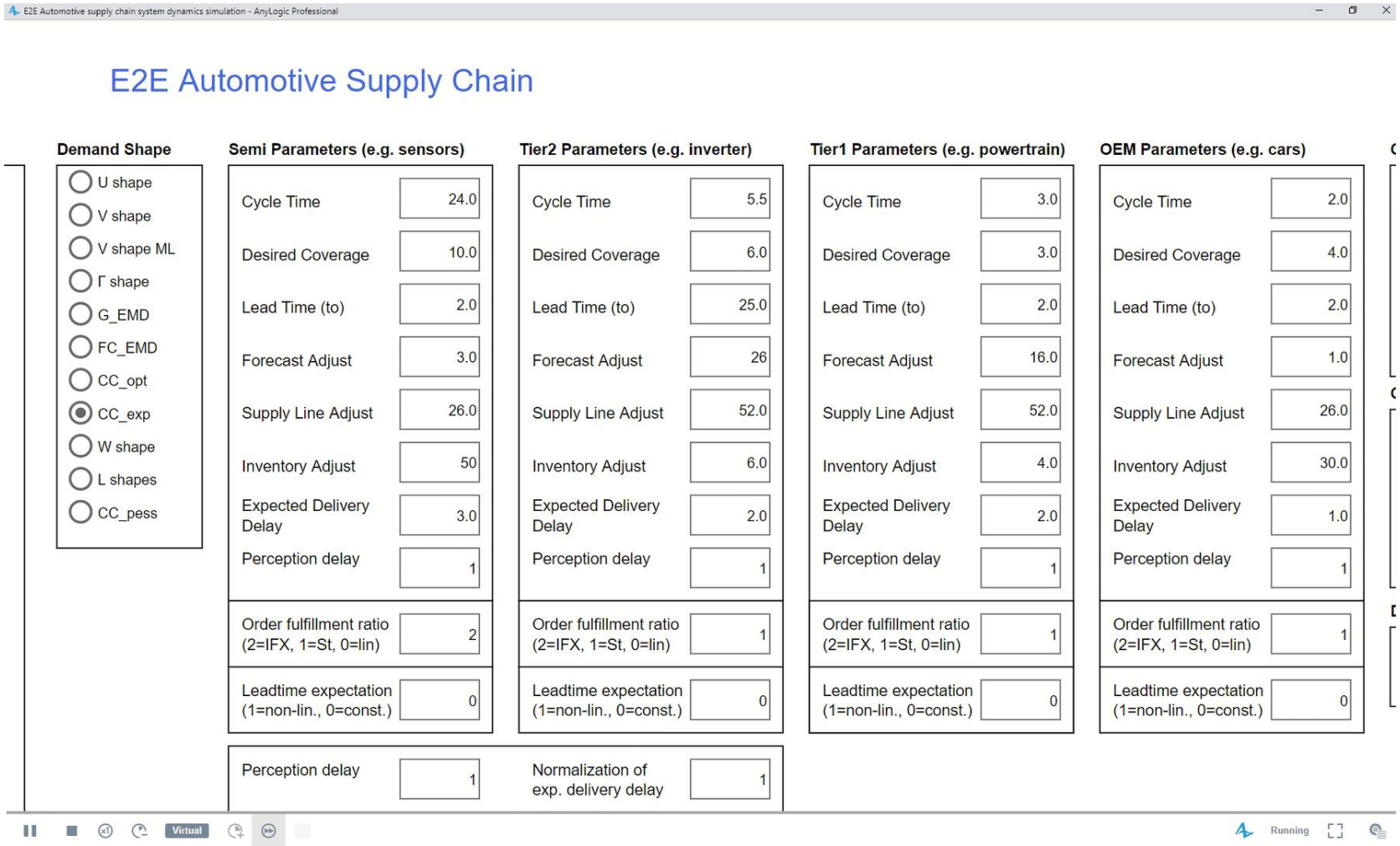
Dashboard E2E simulation model

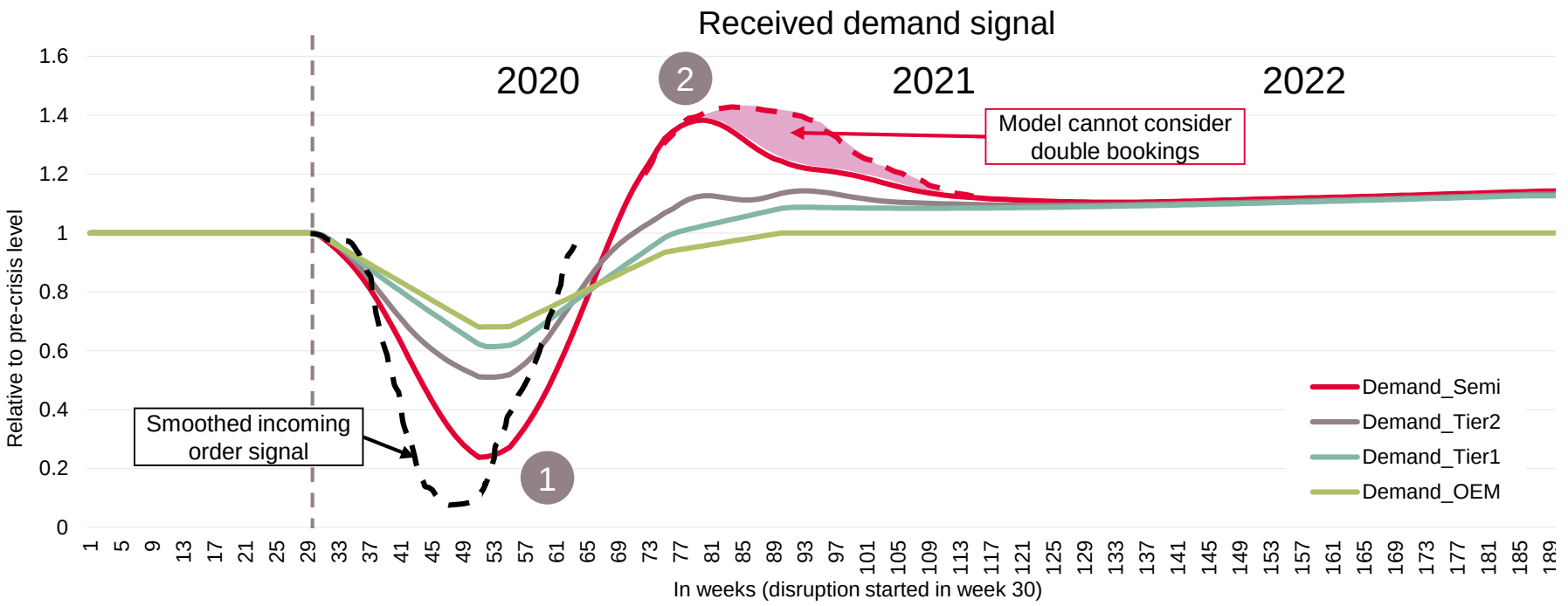


- Simulation dashboard allows for varying a wide range of different parameters for a scenario analysis

Demo simulation model with Semiconductor manufacturers as Tier-3 – COVID-19 end market demand scenario



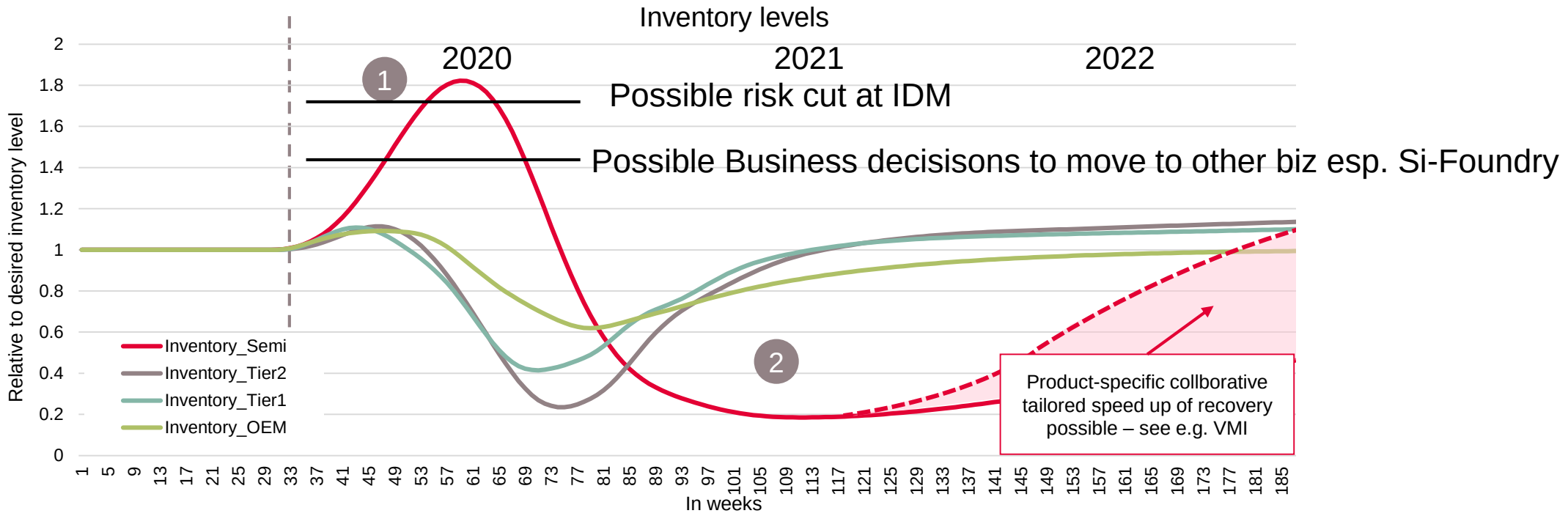
After the demand for semiconductors collapsed during the pandemic orders harshly recovered during end market demand recovery



1. The results of the simulation model show a clear **amplification of the change** in the end market for light vehicle sales. The more upstream in the supply chain, the larger the drop in the received demand signal during the crisis.

2. The recovery phase in end market demand shows high amplification of demand increase. The incoming demand for the semiconductor echelon **exceeds end market demand** by about 40% with a doubled amplification compared to Tier-2.

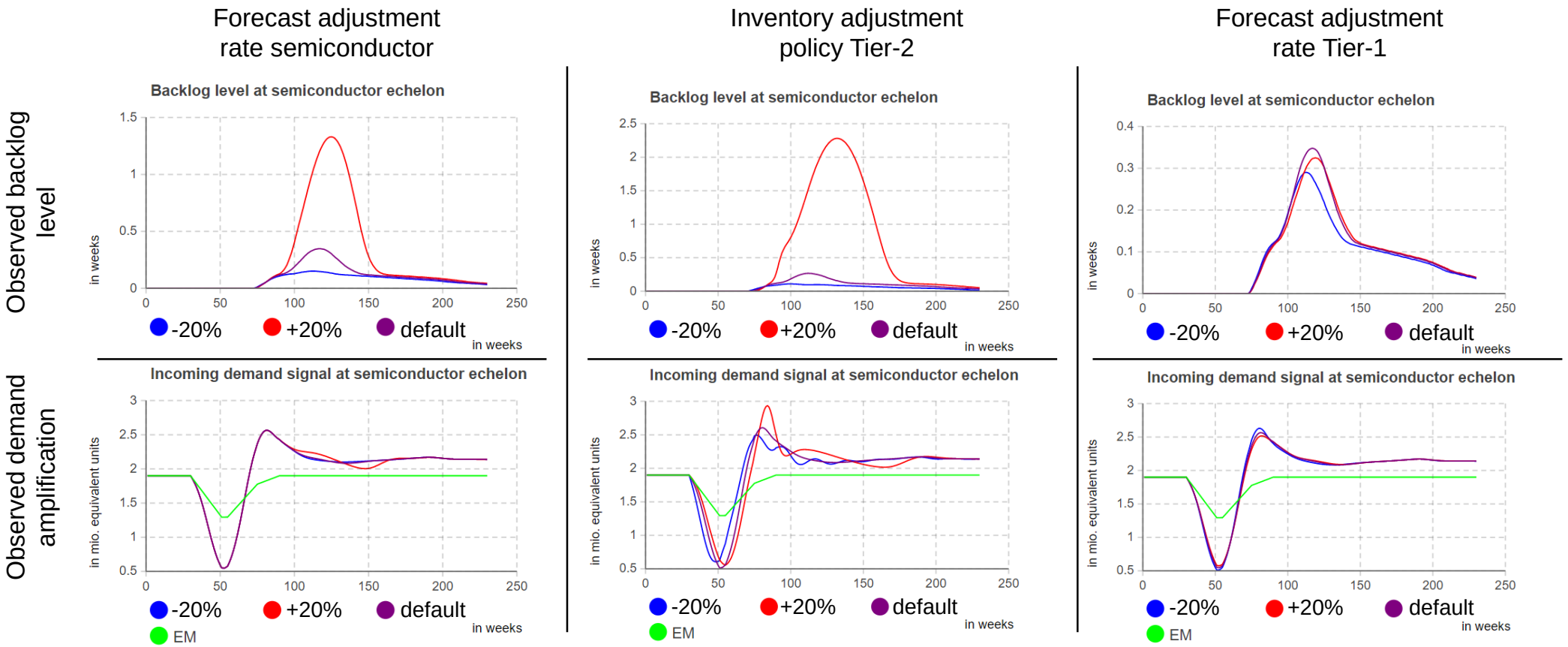
Inventory recovery is challenging due to long cycle times and high demand during the recovery – leads to semiconductor shortage



1. Inventory at semiconductor echelon rises due to cancellation of orders from downstream supply chain partners. Inventory of semiconductor echelon cannot be adapted as flexible due to long cycletimes.

2. In the recovery phase of the crisis, the **inventory level** of the semiconductor echelon is **insufficient**. Due to capacity restriction and high demand from downstream echelon, the inventory level recovers slowly.

Sensitivity analysis for different echelons and parameters indicates future direction for increasing overall supply chain performance



Different behavioral parameters show diverse influence on the backlog level towards Tier-2 supplier, hence, chip shortage for the whole supply chain. More up-to-date and lower time lag in information flow **reduces backlog level**.

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Conclusion & Managerial insights

Amplitude of the demand amplification and oscillation in the supply chain varies according to recovery scenario and behavioral parameters of the individual echelons

Upstream members of supply chain suffer the most from the disruption and restoring equilibrium might last longer. Reaction during demand drop affects ability to cope with recovering demand.

Collaboration and trust are important to master the bullwhip effect. Communication in terms of ordering behavior, inventory coverage and lead time communication can improve the situation.

At Infineon a VMI KPI improvement concept has been developed to give more insight into downstream/upstream root causes.

Next steps for the simulation model

Investigation of region specific behavior, e.g., some regions recovered faster than others, and considerations of different semiconductor applications

Exploration of limitations in the assembly stop of downstream echelons due to shortage of one single product (knock-out behavior)

Considerations of new forms of collaboration across entire supply chain, e.g., more direct communication among supply chain echelons for more accurate forecasting and capacity planning (usage of shown simulation platform for collaboration) – Anylogic as a platform that enable this collaboration

Thank you for your attention!

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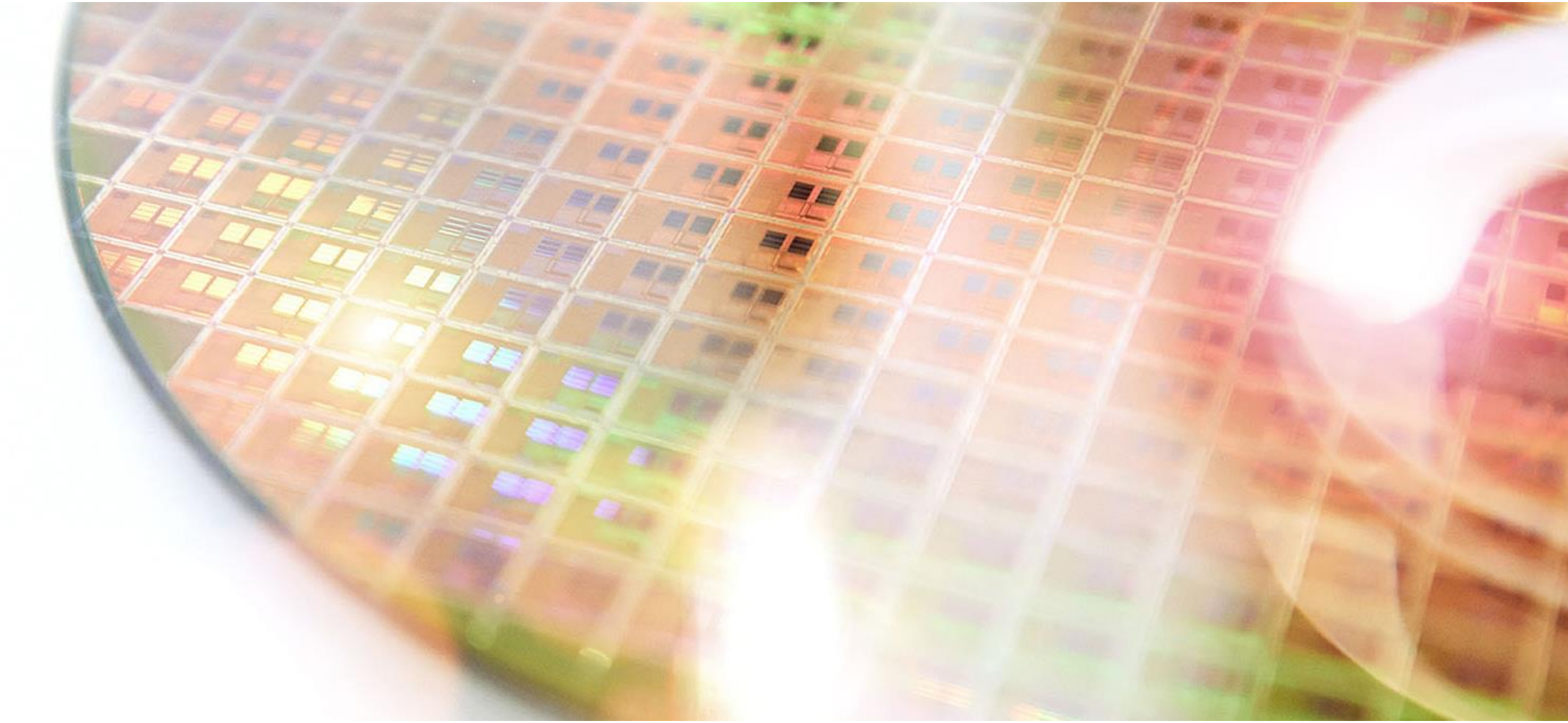
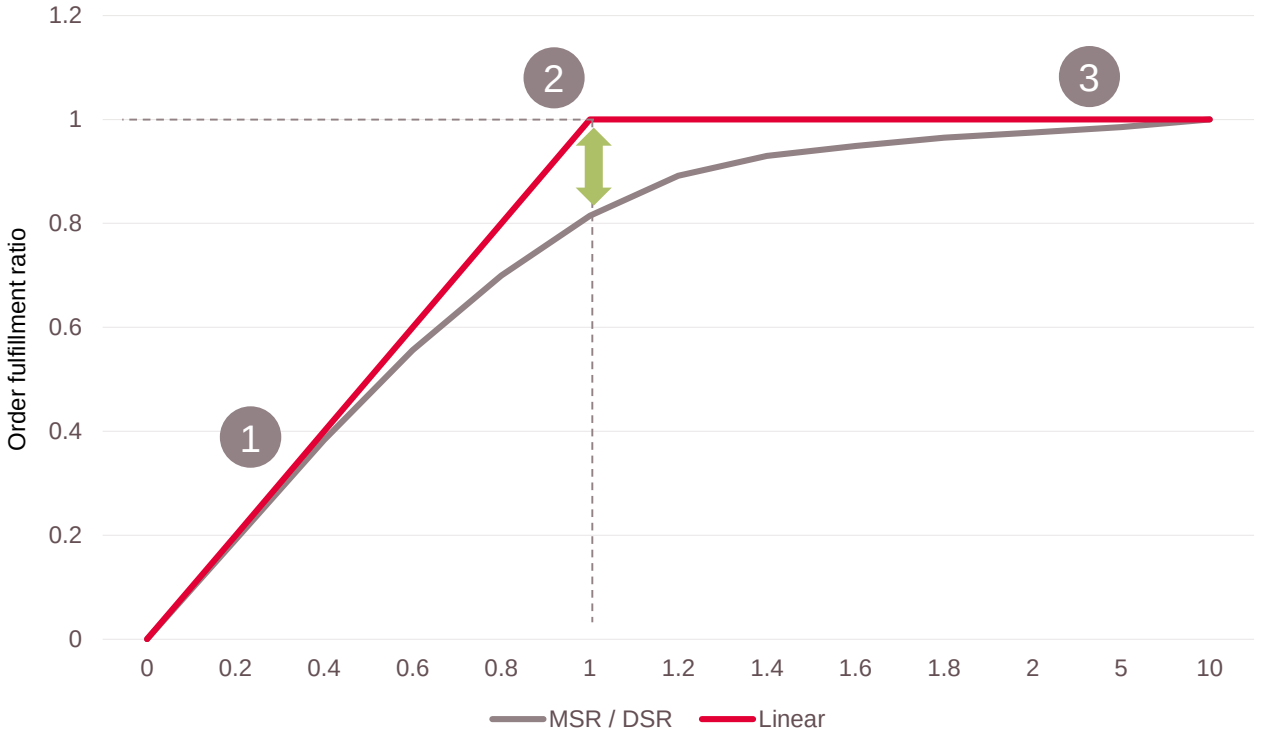
Backup slides



Introduction of a non-linear order fulfillment function to consider a more realistic inventory management behavior

Resulting order fulfillment ability



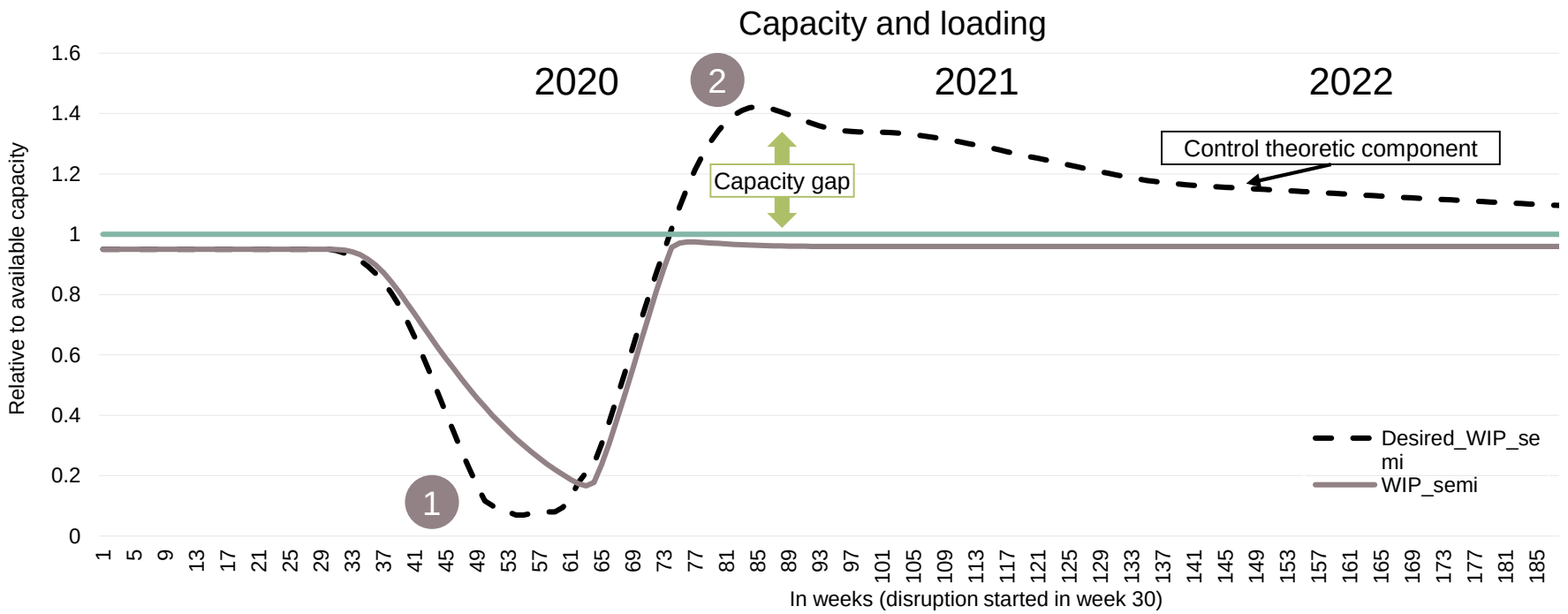
MSR: maximum shipment rate (dependent on inventory level)
DSR: desired shipment rate to the customer

Implications for the simulation model

1. In the beginning almost linear relationship between shipment ratio and order fulfillment
2. Non-linear relationship* when maximum and desired shipment level are similar, due to complex product portfolio
3. When firm has ample inventories, so that maximum aggregate shipment rate is much greater than desired shipment rate, chance that individual item will be out of stock is negligible

* Source: Adopted version of Sterman (2000), Business dynamics

Semiconductor production cannot follow desired production due to inherently long cycle time of complex semiconductor products

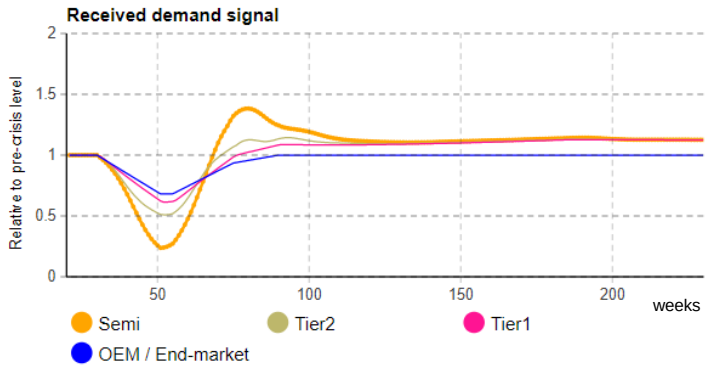


1. During the harsh drop in the end market, i.e. light vehicle sales, the **desired work-in-process drops substantially**, while the actual work-in-process cannot be adapted as quickly due to semiconductor specific features, e.g., the high cycletime.
2. During the recovery phase of the end market demand, the **desired work-in-process exceeds existing capacity** by far. The magnitude depends on the capacity management, e.g., reallocation, but in general this shortage leads to allocation.

The simulation model provides insights into…

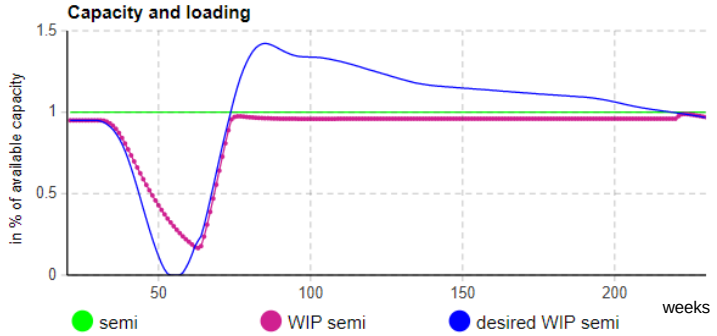
1 Demand amplification

Insights into resulting bullwhip effects



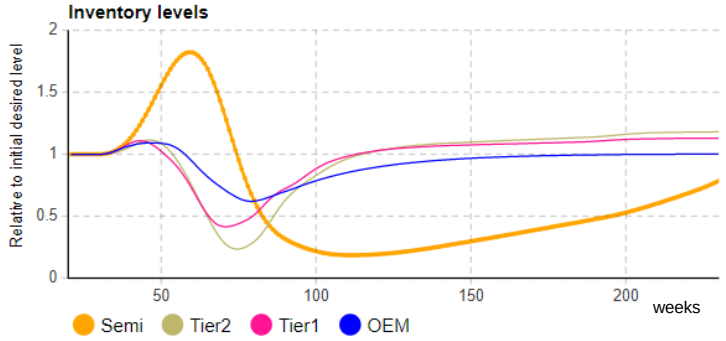
2 Capacity and loading

Capacity loading expected above 100% for long period



3 Inventory levels

Indication of chip shortage due to low inventory level



4 Demand fulfillment and backlog levels

Inability to fulfill 100% of customer orders