ODD+D protocol

The table below is a systematic description as proposed by Müller *et al.* (2013) of the agent-based model titled "Automation-induced Reshoring - An Agent-based Model of the German Manufacturing Industry" developed by Laura Merz.

		Guiding questions	ODD+D model description
I) Overview	I.i Purpose	I.i.a What is the purpose of the study?	This study adds novelty to the extant literature on automation-induced reshoring by offering a system understanding on how the behaviour of firms, guided by simple economic rules on the micro-level, is dynamically influenced by their complex environment in regard to identified relocation decision-making hypotheses. Informed by previously developed economic models, the research attempts to replicate the observed regularities in order to add to the particular understanding of how related sustainability aspects have an impact on reshoring production.
		I.ii.b For whom is the model designed?	○ Scientists ○ Economists ○ Political decision makers
	I.ii Entities, state variables, and scales	I.ii.a What kinds of entities are in the model?	○ <u>One type of agent:</u> German manufacturing firms either located at home or abroad ○ <u>Two types of geographic environments:</u> Germany and an unspecified production location in the Global South

		I.ii.b By what attributes (i.e. state variables and parameters) are these entities characterised?	Of firms: Capital, firm size defined by the size of capital, maximum level of automation, current level of automation, costs for maintaining and running automated production, number of utilised robots, number of total labour units required, actual low-skilled labour ratio, actual high-skilled labour ratio, number of low-skilled labour employed, number of high-skilled labour employed, number of total labour employed, planned budget for labour costs, actual labour costs, raw material costs, production output, revenue, investment in research and development (R&D), relocation costs, profit, label reporting the status of location, economically strategic decision-making Of the manufacturing industry: Number of firms, price for raw material, share of automated firms, costs per robot, robot productivity, threshold at which robots eliminate low-skilled jobs, labour productivity, low-skilled labour ratio, high-skilled labour ratio, share for R&D investment, share for relocation costs, sales price for finished product Of the German economy: Wages for low-skilled labour, wages for high skilled labour Of the foreign economy: Wages for low-skilled labour, wages for high skilled labour, share of offshored firms, foreign surcharges
		I.ii.c What are the exogenous factors / drivers of the model?	Generally: Exponential economic growth, non-competing economic market, dynamics of the financial market (such as currency fluctuation, exchange rates, inflation rate), labour market, various supplier networks, customer base, domestic politics, international relations, legal circumstances, R&D Specifically: Price for raw material, foreign surcharges, sales price for finished product, relocation costs, wages, robot productivity,

			human labour productivity, technological innovation
		I.ii.d If applicable, how is space included in the model?	The modelling world is divided in a Global North and Global South, whilst agents move from one geographic location to the other depending on their relocation decision.
		I.ii.e What are the temporal and spatial resolutions and extents of the model?	Yearly time steps representing business cycles with a simulation length of 100 ticks. Relocation decisions are taken on the basis of the annual financial statement at the end of the year meeting. Firms are distributed randomly across their geographic production location. The exact location is inconsequential.
	I.iii Process overview and scheduling	I.iii.a What entity does what, and in what order?	<u>Set-up of the economy:</u> 1. Modelled world is set according to the North-South divide, colouring Germany in the North in blue, the equator as a border white, and the abstracted Global South in yellow 2. Creation of a defined number of firms <u>Set-up of the industry:</u> **1. Set-up firms:** Defines the initial parameter values of firms. The initial seed capital is a random value between >0 and <1000 and the maximum level of attainable efficiency in automation is defined as a fixed random value between >0 and <1. ask *firms [* set *working-capital random 1000* set *max-level-of-automation 0 + random-float 1]* **2. Offshoring:** Initially, all firms report that they have neither offshored nor reshored. Defined by

a given share, the initial number of offshored firms is calculated. Firms with a lower attainability of automation have a higher incentive to offshore where manual labour is cheaper. The firms are then distributed on the modelled economy according to their location, but randomly on the map of the respective country.

```
ask firms [
    set offshored? false
    set reshored? false
    let offshored-firms ( min-n-of ( count firms * ( share-of-offshored-firms / 100 ) ) firms [ max-level-of-automation ] )
ask offshored-firms [
    setxy random-xcor random-between ( -10 ) -1
    set offshored? true ] ]
ask firms with [ offshored? = false ] [
    setxy random-xcor random-between ( 10 ) 1
```

3. **Tech-state-of-the-art:** States the firms' technological state of the art. Only a defined share of firms already utilises robots at the initial set-up. The current efficiency of automated production is a random value between >0 and the specified maximum attainable level of automation. A dark orange colour shading depicts a low level of automation, whereas a light orange stands for high levels of automation.

```
ask n-of ( count firms * ( share-of-automated-firms / 100 ) ) firms [
    set level-of-automation random-between ( 0.01 ) max-level-of-automation ]
ask firms [
    set color scale-color orange level-of-automation 0 1 ]
```

4. **Costs-calculation:** Firstly, the amount covering raw material costs is allocated by a defined share. The working capital is then divided into raw material costs and the budget allocated for covering labour wages.

```
ask firms [
    set raw-material-costs working-capital * ( share-of-raw-material-costs / 100 )
    set budget-for-labour-costs working-capital - raw-material-costs ]
```

5. **Human-vs-robot:** Defines the ratios of low-skilled human labour, high-skilled human labour, and robots required for production. Firstly, the ratio of high-skilled labour is calculated in proportion to a defined ratio of low-skilled labour. If the technological threshold at which robots eliminate all low-skilled jobs is reached, all low-skilled labour becomes obsolete and labour is shared between high-skilled labour and robots. If this is not the case, the division of labour is calculated depending on the current level of automation, as well as the defined ratio for low-skilled and high-skilled labour.

```
ask firms [
    set high-skilled-labour-ratio 1 - low-skilled-labour-ratio
    ifelse ( level-of-automation >= robots-kill-jobs-threshold ) [
    set actual-low-skilled-labour-ratio 0
    set actual-high-skilled-labour-ratio 1 - level-of-automation ] [
    set actual-low-skilled-labour-ratio ( 1 - level-of-automation ) * low-skilled-labour-ratio
    set actual-high-skilled-labour-ratio ( 1 - level-of-automation ) * high-skilled-labour-ratio ] ]
```

6. **Employment:** Calculates the type of labour units employed or utilised. Ratios determine the varying shares of the three different types of labour units, namely low-skilled labour, high-skilled labour, and robots. Further, the budget allocated for covering the different labour unit costs and wages is calculated. The planned budget is then squared with the actual amount of labour units which can be afforded for production of this business cycle. These numbers show how many human labour units are actually employed for production. Equally, it is shown how many labour units are utilised in total. The calculations differ depending on the geographic location of the production facilities.

```
ask firms [
    let budget-for-robots budget-for-labour-costs * level-of-automation
    let budget-for-low-skilled-labour budget-for-labour-costs * actual-low-skilled-labour-ratio
    let budget-for-high-skilled-labour budget-for-labour-costs * actual-high-skilled-labour-ratio
    set robots floor ( budget-for-robots / robot-costs )
    set low-skilled-labour floor ( budget-for-low-skilled-labour / wages-low-skilled-labour )
    set high-skilled-labour floor ( budget-for-high-skilled-labour / wages-high-skilled-labour )
    set human-labour low-skilled-labour + high-skilled-labour
    set labour-units robots + low-skilled-labour + high-skilled-labour
    set low-skilled-labour-abroad floor ( budget-for-low-skilled-labour / wages-low-skilled-labour-abroad )
```

set *high-skilled-labour-abroad floor (budget-for-high-skilled-labour / wages-high-skilled-labour-abroad)*

set *human-labour-abroad low-skilled-labour-abroad + high-skilled-labour-abroad*

set *labour-units-abroad robots + low-skilled-labour-abroad + high-skilled-labour-abroad*

Consequently, the actual numbers of afforded labour units define the actual budget covering labour wages and robot utilisation. Calculations again differ depending on the geographic location of the production facilities.

ask *firms [*

ifelse *(offshored? = false) [*

set *actual-labour-costs (low-skilled-labour * wages-low-skilled-labour) + (high-skilled-labour * wages-high-skilled-labour)*

set *automation-costs robots * robot-costs] [*

set *actual-labour-costs (low-skilled-labour-abroad * wages-low-skilled-labour-abroad) + (high-skilled-labour-abroad * wages-high-skilled-labour-abroad)*

set *automation-costs robots * robot-costs]]*

7. **Output-calculation:** Calculates the amount of produced goods. The amount of output differs between human labour and robots due to varying levels of productivity. As different numbers of labour units are employed and utilised in Germany in comparison to offshore production, also this calculation varies.

ask *firms [*

set *output (human-labour * labour-productivity) + (robots * robot-productivity)*

set *output-abroad (human-labour-abroad * labour-productivity) + (robots * robot-productivity)]*

8. **Revenue-calculation:** Calculates the total income received by selling produced goods to a global sales price. The revenue is computed twice due to the fact that the output varies between the two alternative production locations as described above.

ask *firms [*

set *revenue output * sales-price-per-product*

set *revenue-abroad output-abroad * sales-price-per-product]*

9. **R&D-calculation:** Allocates the particular share of revenue invested in R&D. As revenues differ between the two geographic locations, the share invested in R&D logically differs as well. If the current level of automation however reaches its maximum attainable level, investment in R&D is no longer needed and, hence, is set to zero.

ask *firms [*

set *r&d-investment revenue * (share-for-r&d-investment / 100)*

set *r&d-investment-abroad revenue-abroad * (share-for-r&d-investment / 100)*

if *level-of-automation = max-level-of-automation [*

set *r&d-investment 0*

set *r&d-investment-abroad 0]]*

10. **Profit-calculation:** When production is offshore, a defined percentage of revenue is additionally required for foreign surcharges (e.g. shipping costs or import tariffs). Only then, the net financial gain at the end of a business cycle is calculated. Two

differing calculations are yet again required here due to geographically differing circumstances.

ask *firms [*

set *foreign-surcharges revenue-abroad * (share-for-foreign-surcharges / 100)*

set *profit revenue - r&d-investment*

set *profit-abroad revenue-abroad - r&d-investment-abroad - foreign-surcharges]*

11. **Firms-size-ratio:** Defines the size of firms in relation to firms' seed capital. The 10 % firms with the highest value of seed capital are large in size. Firms which are not particularly low or high in seed capital are of medium size. And the 30 % firms with the lowest value of seed capital are small in size. The firms are shaped as factory facilities for visualisation purposes.

ask *firms [*

set *firm-size "medium"*

set *size 1*

set *shape "house"]*

ask *(max-n-of (number-of-firms * 0.1) firms [working-capital]) [*

set *firm-size "large"*

set *size 1.5*

set *shape "house"]*

ask *(min-n-of (number-of-firms * 0.3) firms [working-capital]) [*

set *firm-size "small"*

set *size 0.5*

set *shape "house"]*

Go:

12. **Stocktaking of working capital:** Working capital of the coming business cycle is calculated by deducting last time periods'

liabilities from the assets. Calculations differ depending on the production location.

ask *firms [*

ifelse *(offshored? = false) [*

set *working-capital working-capital - raw-material-costs - actual-labour-costs - automation-costs + profit] [*

set *working-capital working-capital - raw-material-costs - actual-labour-costs - automation-costs + profit-abroad]]*

13. **Technological-progress:** Firstly, the condition whether the current level of automation has reached the maximum attainable level is inquired. If this is the case, the R&D investment logically cannot increase the level of automation beyond that value. Otherwise, the efficiency of automated production increases proportional to the R&D investment. The calculation differs between firms which produce in Germany and the ones which are offshore.

ask *firms with [offshored? = false] [*

ifelse *((level-of-automation + r&d-investment) < max-level-of-automation) [*

set *level-of-automation level-of-automation + r&d-investment] [*

set *level-of-automation max-level-of-automation]]*

ask *firms with [offshored? = true] [*

ifelse *((level-of-automation + r&d-investment-abroad) < max-level-of-automation) [*

set *level-of-automation level-of-automation + r&d-investment-abroad] [*

set *level-of-automation max-level-of-automation]]*

ask *firms [*

set *color scale-color orange level-of-automation 0 1]*

14. **Costs-calculation:** See elaboration above.

15. **Human-vs-robot:** See elaboration above.

16. **Employment:** See elaboration above.

17. **Output-calculation:** See elaboration above.

18. **Revenue-calculation:** See elaboration above.

19. **R&D-calculation:** See elaboration above.

20. **Profit-calculation:** See elaboration above.

21. **Location-decision:** States the conditions of decision-making concerning relocation. Depending on the geographic location on the modelled world, the specific percentage of profit required for relocation is calculated. If the profit when producing in the current production location is smaller than the profit the firm could have generated if located at the alternative location despite taking relocation costs into account, than the firm decides to move production, namely re- or offshore. For visualisation purposes, the agent is asked to move to a spot on the modelled map where there is no other agent already located. At the end of the decision-making process, the conclusion is reported.

ask *firms with [offshored? = false] [*

set *relocation-costs (share-for-relocation-costs / 100) * profit*

if *(profit < (profit-abroad - relocation-costs)) [*

move-to *one-of patches with [pcolor = 48 and not any? turtles-here]*

set *offshored? true*

set *reshored? false]]*

ask *firms with [offshored? = true] [*

set *relocation-costs (share-for-relocation-costs / 100) * profit-abroad*

if *(profit-abroad < (profit - relocation-costs)) [*

move-to *one-of patches with [pcolor = 98 and not any? turtles-here]*

set *offshored? false*

set *reshored? true]]*

22. **Firms-size-ratio:** Defines the size of firms in relation to firms' working capital. The sizing corresponds with the one at initial set-up of the industry.

23. **Bankruptcy:** States the conditions leading to bankruptcy. When firms reach a specified threshold, they are no longer part of the economy.

ask *firms [*

if *working-capital <= 10 [die]]*

24. **Tick:** Advances the tick counter by one time period.

tick

25. States the length of each simulation run:

if *ticks = 100 [stop]*

II) Design Concepts	II.i Theoretical and Empirical Background	II.i.a Which general concepts, theories or hypotheses are underlying the model's design at the system level or at the level(s) of the submodel(s) (apart from the decision model)? What is the link to complexity and the purpose of the model?	The model design follows mainstream neoclassical economic concepts and theories.
			Inspired by studies of: (Eliasson *et al.* 1976; Deissenberg *et al.* 2008; Erlingsson *et al.* 2014)
			Suggested in studies of: Janssen (2005); LeBaron & Tesfatsion (2008); Neugart & Richiardi (2012); van Dam *et al.* (2013); Tate *et al.* (2014); Rose & Reeves (2017)
		II.i.b On what assumptions is/are the agents' decision model(s) based?	**Based on established microeconomic theories:** *Homo oeconomicus* (capital calculation, output calculation, calculation of investment and surcharges, revenue calculation, profit calculation)
			Following real-world observations: Identified and outlined problem statement of studied phenomenon in extant literature including previous economic models (e.g. Wiesmann *et al.* 2017; Krenz *et al.* 2018)
		II.i.c Why is a/are certain decision model(s) chosen?	In reference to previous economic models, theoretical considerations follow established concepts in order to ensure scientific reliability of the model. Further, the availability of national statistics guaranteed independent data collection.
		II.i.d If the model / a submodel (e.g. the decision model) is based on empirical	Some of the parameter values are chosen at random during the calibration process of the model whilst

		data, where does the data come from?	directly observing the behaviour of the modelled dynamics.
		II.i.e At which level of aggregation were the data available?	National level
	II.ii Individual Decision Making	II.ii.a What are the subjects and objects of decision-making? On which level of aggregation is decision-making modelled? Are multiple levels of decision making included?	<u>Subjects:</u> Individual firms on the microeconomic level <u>Objects of decisions:</u> Technological progress, cost calculation, labour unit ratio (human labour versus robots), employment, output calculation, revenue calculation, R&D calculation, profit calculation, bankruptcy The relocation decision is made at the end of each simulated business cycle. Over the simulation, all steps of production, as well as cost calculations, aggregate, adding to the final decision-making process.
		II.ii.b What is the basic rationality behind agents' decision-making in the model? Do agents pursue an explicit objective or have other success criteria?	Decision-making in the model follows rational choice theory aiming at the maximisation of utility.
		II.ii.c How do agents make their decisions?	The decision tree is based on the function of utility maximisation. This means that decisions are solely based on economic profitability.
		II.ii.d Do the agents adapt their behaviour to changing endogenous and exogenous state variables? And if yes, how?	Adaption is dependent on: <u>Endogenous variables:</u> o **Level of automation** (with an increased level of automation, the firm utilises more robots and hires less human labour which has an effect on the costs for automation as well as the costs for labour wages) o **R&D investment** (as soon as the maximum level of automation is reached, the firms stop to invest in

			R&D which also means that a larger share of the revenue can be entered as profit) ○ **Relocation costs** (as the costs needed for relocation are a share of the profit, they are recalculated prior to each relocation decision) ○ **Profits** (after deducting the costs from the income, the profit of that business cycle is determined) ○ **Capital** (depending on the profit of the previous business cycle, firms have more or less capital to spend on production operations of the coming period) <u>Exogenous variables:</u> ○ **Low-skilled and high-skilled labour ratio** (depending on this ratio, it is determined which mix of skillset is needed to produce goods. This will then have an effect on labour wages as low-skilled and high-skilled workers are paid different wage levels) ○ **Level of wages** (changed levels of wages in the respective countries determine how many workers can be employed given the planned budget for labour unit costs) ○ **Automation costs** (changing the costs for running and maintaining automated production determines how many industrial robots can be utilised given the planned budget for labour unit costs) ○ **Share required for foreign surcharges** (varying shares indicate more or less revenue respectively) ○ **Share required for relocation costs** (varying shares indicate more or less profit respectively)
		II.ii.e Do social norms or cultural values play a role in the decision-making process?	-

		II.ii.f Do spatial aspects play a role in the decision process?	Yes. Dependent on whether firms produce in Germany or abroad, different national wage levels are determining a firm's ability to hire more or less workers respectively. Within the country, the wages between low-skilled and high-skilled labour yet again differs. Also, there are foreign surcharges (e.g. shipping costs or import tariffs) which only apply when production is located abroad.
		II.ii.g Do temporal aspects play a role in the decision process?	Yes. Accounting is cumulative which means that the financial balance sheet of each business cycle aggregates onto the economic performance of the previous time steps. Next to aggregating economic indicators, the level of automation is assumed to rise in proportion to a firm's R&D investment. As soon as the maximum level of automation is reached, this value stays fix and the investment costs for R&D drop to zero from this point onwards. Depending on the level of automation, as well as the threshold at which robots eliminate low-skilled jobs, the ratio of utilised robots versus human workers adjusts accordingly at every time step.
		II.ii.h To which extent and how is uncertainty included in the agents' decision rules?	-
	II.iii Learning	II.iii.a Is individual learning included in the decision process? How do individuals change their decision rules over time as consequence of their experience?	-
		II.iii.b Is collective learning implemented in the model?	-
	II.iv Individual Sensing	II.iv.a What endogenous and exogenous state variables are individuals assumed to sense and consider in their decisions? Is the sensing process erroneous?	<u>Endogenous state variables:</u> ○ Internal business operations including administration, scouting, hiring process, etc. ○ Business competition <u>Exogenous state variables:</u> ○ Natural resource supply

			○ Labour market (unlimited pool of low-skilled and high-skilled labour is assumed) ○ Sales market ○ Financial market ○ Dynamics of a competitive market economy
		II.iv.b What state variables of which other individuals can an individual perceive? Is the sensing process erroneous?	-
		II.iv.c What is the spatial scale of sensing?	The spatial scale includes the individual firm-level, as well as the national and global level.
		II.iv.d Are the mechanisms by which agents obtain information modelled explicitly, or are individuals simply assumed to know these variables?	Profit calculations occur on the local, namely the microeconomic level following a specific timely order mimicking a yearly business cycle. Global information is directly accessible by any agent at any time.
		II.iv.e Are costs for cognition and costs for gathering information included in the model?	-
	II.v Individual Prediction	II.v.a Which data uses the agent to predict future conditions?	Firms use data from financial sheets of past business cycles to predict future conditions.
		II.v.b What internal models are agents assumed to use to estimate future conditions or consequences of their decisions?	The unique process of this model is the direct comparison of a double-entry balance sheet. More specifically, this means the profit calculation of operations in the current production location to the profit which could have been generated in the alternative destination. As national parameters and exogeneous factors do not change within simulation runs, balancing of accounts can be predicted accurately.
		II.v.c Might agents be erroneous in the prediction	-

		process, and how is it implemented?	
	II.vi Interaction	II.vi.a Are interactions among agents and entities assumed as direct or indirect?	There are no direct nor indirect interactions among agents. Agents however interact directly with the modelled economy.
		II.vi.b On what do the interactions depend?	Geographic location
		II.vi.c If the interactions involve communication, how are such communications represented?	-
		II.vi.d If a coordination network exists, how does it affect the agent behaviour? Is the structure of the network imposed or emergent?	-
	II.vii Collectives	II.vii.a Do the individuals form or belong to aggregations that affect, and are affected by, the individuals? Are these aggregations imposed by the modeller or do they emerge during the simulation?	The geographic location determines the two type of agents. There are firms which produce in Germany and others which offshored production. The share of these two types is initially assigned by the modeller, but as firms have the ability to relocate, firms might move back and forth, hence changing their classification.
		II.vii.b How are collectives represented?	The two different types of agents are equipped with separate kinds of entities depending on their production location, as well as own state variables and traits.
	II.viii Heterogeneity	II.viii.a Are the agents heterogeneous? If yes, which state variables and/or processes differ between the agents?	Yes, the agents are initially provided with heterogeneous state variables. These are the seed capital, the current technological state of the art, the initial selection of firms which are set abroad, as well as the maximum level of automation.
		II.viii.b Are the agents heterogeneous in their decision-making? If yes, which decision models or decision objects differ between the agents?	The decision-making is heterogeneous in the sense that firms which produce abroad have to take additional costs (here: foreign surcharges) into account. For firms producing in Germany, there are no extra

			costs, as the sales market is assumed to be in Germany.
	II.ix Stochasticity	II.ix.a What processes (including initialization) are modelled by assuming they are random or partly random?	All of the heterogeneous state variables differentiate at initial set-up which means that they significantly influence the outcome of all following processes as the lead conditions vary among each and every firm. More specifically, this means that all business internal calculations of each company start off with their given seed capital. A firm's current level of automation determines how many human labour units are employed, as well as how many robots are utilised. Further, it is assumed that firms with a lower attainability of automation have a higher incentive to offshore where manual labour is cheaper. This is why the initial share of offshored firms are the ones with the lowest value of maximum levels of automation. The maximum level of automation delimits the attainable technological progress.
	II.x Observation	II.x.a What data are collected from the ABM for testing, understanding, and analysing it, and how and when are they collected?	<u>Testing via parameter sweeping:</u> After validating the behaviour of the model to mimic the real-world phenomenon under study, the model was then tested via parameter sweeping (CSP-AIMS 2015). First, analysis was manual at random which aimed at identifying parameters which are observably relevant for significantly modifying the behaviour of the ABM. In order to answer the research question of the conducted study, the main focus lied upon parameters related to sustainability. In order to allow for an environmental angle to the studied topic, foreign surcharges were analysed, as well as fluctuating labour wages in Germany and abroad in order to study the social dimension of reshoring. Further, these specific parameters were tested through a methodologically more ordered approach, utilising *NetLogo*'s simulation tool 'BehaviorSpace' (García Vázquez & Sancho Caparrini 2016). The purpose of this approach includes the systematic performance of a vast number of experiments in an automated manner. The

			logic behind testing the values selected was to allow for a minimum and maximum range, as well as a more sensitive range around the initially calibrated value. The data was further analysed using the statistical computing environment *R* (R Core Team 2019).
		II.x.b What key results, outputs or characteristics of the model are emerging from the individuals? (Emergence)	Allowing for an agent-based perspective allowed insights on how the behaviour of firms, guided by simple economic rules on the micro-level, is dynamically influenced by the complexity of their surrounding environment. Hypotheses related to environmental and social sustainability aspects have been tested in regard to their sensitivity to initial condition. The computational simulations served as a virtual lab for demonstrating how increased environmental regulations targeting global trade and upward shifting wage levels in formerly offshore production locations are key driving and inhibiting mechanisms of this socio-technical system. This has shown the importance of the aforementioned drivers and barriers, next to the role of technological innovations as the main key determinants of shifted economic realities leading to the phenomenon of reshoring.
III) Details	II.i Implementation Details	III.i.a How has the model been implemented?	<u>Computer system:</u> *NetLogo* <u>Programming language:</u> Logo <u>Simulation platform:</u> BehaviorSpace <u>Simulation runtime:</u> 100 ticks <u>Development time:</u> January 15th, 2019 until May, 16th 2019

		III.i.b Is the model accessible and if so where?	Will be accessible on the *OpenABM* library: https://www.comses.net/
	III.ii Initialisation	III.ii.a What is the initial state of the model world, i.e. at time t=0 of a simulation run?	Variable: **number-of-firms** Description: describes the total number of firms representing the modelled economy Initial value: 100 Unit: firm Variable: **firm-size** Description: defines the size of the firms depending on their working capital Initial value: small, medium, or large Unit: size of working capital Variable: **share-of-offshored-firms** Description: percentage of firms which initially offshored production Initial value: 8 % Unit: percentage Variable: **offshored?** Description: label reporting whether production is offshored or not [path-dependent] Initial value: true or false Unit: label Variable: **working capital** Description: difference between a firm's current assets and liabilities Initial value: random between >0 and <1000 Unit: euros Variable: **share-of-raw-material-costs** Description: percentage of working capital allocated to cover raw materials costs

Initial value: 50 %

Unit: percentage

Variable: **share-of-labour-costs**

Description: percentage of working capital allocated for covering labour wages (Perloff, 2016)

Initial value: 50 %

Unit: percentage

Variable: **low-skilled-labour-ratio**

Description: ratio of low-skilled labour required for production [random]

Initial value: 0.8

Unit: ratio

Variable: **high-skilled-labour-ratio**

Description: ratio of high-skilled labour required for production [random]

Initial value: 0.2

Unit: ratio

Variable: **wages-low-skilled-labour**

Description: yearly salary per low-skilled worker in Germany [random]

Initial value: 11

Unit: euros

Variable: **wages-high-skilled-labour**

Description: yearly salary per high-skilled worker in Germany [random]

Initial value: 12

Unit: euros

Variable: **wages-low-skilled-labour-abroad**

Description: yearly salary per low-skilled worker abroad [random]

Initial value: 10

Unit: euros

Variable: **wages-high-skilled-labour-abroad**

Description: yearly salary per high-skilled worker abroad [random]

Initial value: 11

Unit: euros

Variable: **labour-productivity**

Description: amount of output a human worker produces per time step [random]

Initial value: 1

Unit: ratio

Variable: **max-level-of-automation**

Description: maximum level of attainable efficiency of automated production [random]

Initial value: random between 0 and <1

Unit: ratio

Variable: **level-of-automation**

Description: current level of efficiency of automated production [random]

Initial value: random between 0 and <max-level-of-automation

Unit: ratio

Variable: **share-of-automated-firms**

Description: percentage of firms which initially utilised robots for production (Jäger *et al.,* 2016)

Initial value: 29 %

Unit: percentage

Variable: **robot-costs**

Description: costs for maintaining and running robotic automation (e.g. energy bill) [random]

Initial value: 20

Unit: euros

Variable: **robot-productivity**

Description: amount of output a robot produces per time step [random]

Initial value: 10

Unit: ratio

Variable: **robots-kill-jobs-threshold**

Description: technological threshold at which robots eliminate all low-skilled jobs [random]

Initial value: 0.8

Unit: ratio

Variable: **sales-price-per-product**

Description: global sales price for finished products [random]

Initial value: 20

Unit: euros

Variable: **share-for-r&d-investment**

Description: percentage of revenue allocated for R&D investment [random]

Initial value: 1 %

Unit: percentage

Variable: **share-for-foreign-surcharges**

Description: percentage of revenue which is additionally required if production is offshored (e.g. shipping costs or import tariffs) [random]

Initial value: 1 %

Unit: percentage

Variable: **share-for-relocation-costs**

Description: percentage of profit required in case of relocation [random]

Initial value: 1 %

Unit: percentage

Values of the following variables are path-dependent, meaning that they aggregate only after originating from other variables. This means they are heterogeneous for every single firm:

Variable: **actual-low-skilled-labour-ratio**

Description: calculated ratio accounting for the level of automation which has already replaced low-skilled jobs

Unit: ratio

Variable: **actual-high-skilled-labour-ratio**

Description: calculated ratio accounting for the level of automation which has already replaced high-skilled jobs

Unit: ratio

Variable: **robots**

Description: afforded amount of robots utilised for production

Unit: robot

Variable: **low-skilled-labour**

Description: afforded number of low-skilled labour employed for production in Germany

Unit: human worker

Variable: **high-skilled-labour**

Description: afforded number of high-skilled labour employed for production in Germany

Unit: human worker

Variable: **low-skilled-labour-abroad**

Description: afforded number of low-skilled labour employed for offshored production

Unit: human worker

Variable: **high-skilled-labour-abroad**

Description: afforded number of high-skilled labour employed for offshored production

Unit: human worker

Variable: **human-labour**

Description: number of human labour units employed for production in Germany

Unit: human worker

Variable: **human-labour-abroad**

Description: number of human labour units employed for offshored production

Unit: human worker

Variable: **labour-units**

Description: total number of all labour units employed or utilised for production in Germany

Unit: robots and/ human worker

Variable: **labour-units-abroad**

Description: total number of all labour units employed or utilised for offshored production

Unit: robots and/or human worker

Variable: **budget-for-labour-costs**

Description: initially allocated budget for covering labour wages

Unit: euros

Variable: **actual-labour-costs**

Description: actual budget covering labour wages

Unit: euros

Variable: **automation-costs**

Description: actual budget covering robot utilisation (e.g. energy bill)

Unit: euros

Variable: **output**

Description: amount of produced goods if production is located in Germany

Unit: abstracted product

Variable: **output-abroad**

Description: amount of produced goods if production is offshored

Unit: abstracted product

Variable: **revenue**

Description: total income received by selling produced goods if production is located in Germany

Unit: euros

Variable: **revenue-abroad**

Description: total income received by selling produced goods if production is offshored

Unit: euros

Variable: **r&d-investment**

Description: allocated investment in R&D if production is located in Germany

Unit: euros

Variable: **r&d-investment-abroad**

Description: allocated investment in R&D if production is offshored

Unit: euros

Variable: **foreign-surcharges**

Description: allocated surcharges if production is offshored (e.g. shipping costs or import tariffs)

Unit: euros

Variable: **relocation-costs**

			Description: allocated costs required in case of relocation Unit: euros Variable: **profit** Description: net financial gain at the end of a business cycle if production is in Germany Unit: euros Variable: **profit-abroad** Description: net financial gain at the end of a business cycle if production is offshored Unit: euros Variable: **offshored?** Description: label reporting whether production is offshored or not Initial value: true or false Unit: label Variable: **reshored?** Description: label reporting whether production has been reshored or not Initial value: true or false Unit: label
		III.ii.b Is initialisation always the same, or is it allowed to vary among simulations?	The initialisation of parameters varied during analysis.
		III.ii.c Are the initial values chosen arbitrarily or based on data?	The initial values have been taken from real-world data whenever it seemed sensible to do so. This includes: **share-of-offshored-firms** mimicking the most recent data of the actual percentage stating how many firms within the manufacturing industry have currently offshored production (Jäger *et al.*, 2016); **share-of-automated-firms** which is a value taken from an analysis of robot utilisation showing how many industrial companies in

			Germany have already introduced some level of automation (Jäger *et al.* 2016) The **share-of-raw-material-costs** is inspired by microeconomic textbook examples (Perloff, 2016). Most values have been assigned at random: ○ **number-of-firms** ○ **firm-size** ○ **working-capital** ○ **low-skilled-labour-ratio** ○ **wages-low-skilled-labour** ○ **wages-high-skilled-labour** ○ **wages-low-skilled-labour-abroad** ○ **wages-high-skilled-labour-abroad** ○ **labour-productivity** ○ **max-level-of-automation** ○ **level-of-automation** ○ **robot-costs** ○ **robot-productivity** ○ **robots-kill-jobs-threshold** ○ **sales-price-per-product** ○ **share-for-r&d-investment** ○ **share-for-foreign-surcharges** ○ **share-for-relocation-costs** Exceptions are variables which are dependent on their counterpart: ○ **high-skilled-labour-ratio** (counterpart: low-skilled-labour-ratio) ○ **share-of-labour-costs** (counterpart: share-of-raw-material-costs)
	III.iii Input Data	III.iii.a Does the model use input from external sources such as data files or other models to represent processes that change over time?	No.
	III.iv Submodels	III.iv.a What, in detail, are the submodels that represent the processes listed in 'Process overview and scheduling'?	○ **setup**: sets up the modelled world ○ **setup-economy**: sets up the modelled economy

- **setup-industry**: sets up the modelled industry
- **setup-firms**: sets up the initial values for a firm's seed capital and maximum level of automation
- **offshoring**: determines which firms are initially offshored, namely the ones with the lowest level of attainability when it comes to the maximum level of automation
- **tech-state-of-the-art**: determines how many firms already utilise automation among their production processes, as well as the firms' current level of automation
- **go**: describes the process of one simulation run
- **technological-progress**: determines that firms' level of automation rise in proportion to their R&D investment
- **costs-calculation**: determines how much of working capital is allocated for raw material costs and how much is then left for the budget meant for labour costs
- **human-vs-robot**: according to the defined low-skilled labour ratio, its counterpart, the high-skilled labour ratio is defined. Depending on the level of automation and whether it has already reached the threshold which eliminates all low-skilled jobs, the actual ratios for human labour are calculated.

- **employment**: the planned budget for robot costs and human labour wages are now matched with the current level of automation and the actual human labour ratios respectively. Further, it is determined how many labour units (robots, low-skilled, or high-skilled workers) can be utilised or employed given the planned budget. In reverse, the identified numbers of labour units only then inform about the actual automation and human labour costs.

- **output-calculation**: calculates how much output is produced depending on the actual number of human labour employed, matched with a defined labour productivity. The automation-induced production is likewise depending on the number of robots utilised, matched up with a defined level of efficiency. The produced output is calculated twice, adding to the double-balance sheet in order to allow for comparison during the location decision process.

- **revenue-calculation**: by selling the produced goods to a defined global sales price per product, yielded revenue is similarly calculated twice for the same logic as stated above**.**

- **r&d-calculation**: a defined share of revenue is allocated for investment in R&D and, yet again, defined differently depening on the production location**.** If the current level of automation however reaches the maximum attainable level, the investment is dropped to zero.

- **profit-calculation**: if production is located in Germany, the profits are the made out of the revenue by subtracting the allocated R&D

			investment. For offshore production, foreign surcharges which are a particular share of the revenue, need to be taken into the equation as well. ○ **location-decision**: utilising the aggregated double-balance sheet, the profit of the current production location is directly compared with the profit which could have been generated in the alternative location, given the same business configuration. As an additional hurdle for deciding to relocate production, an extra cost for relocation production facilities factors in here, too. ○ **firms-size-ratio**: determines the size of the various firms according to their working capital ○ **bankruptcy**: described the conditions at which a firm declares bankruptcy
		III.iv.b What are the model parameters, their dimensions and reference values?	Variable: **number-of-firms** Description: describes the total number of firms representing the modelled economy Initial value: 100 Unit: firm Variable: **firm-size** Description: defines the size of the firms depending on their working capital Initial value: small, medium, or large Unit: size of working capital Variable: **share-of-offshored-firms** Description: percentage of firms which initially offshored production Initial value: 8 % Unit: percentage

Variable: **offshored?**

Description: label reporting whether production is offshored or not [path-dependent]

Initial value: true or false

Unit: label

Variable: **working capital**

Description: difference between a firm's current assets and liabilities

Initial value: random between >0 and <1000

Unit: euros

Variable: **share-of-raw-material-costs**

Description: percentage of working capital allocated to cover raw materials costs

Initial value: 50 %

Unit: percentage

Variable: **share-of-labour-costs**

Description: percentage of working capital allocated for covering labour wages (Perloff, 2016)

Initial value: 50 %

Unit: percentage

Variable: **low-skilled-labour-ratio**

Description: ratio of low-skilled labour required for production [random]

Initial value: 0.8

Unit: ratio

Variable: **high-skilled-labour-ratio**

Description: ratio of high-skilled labour required for production [random]

Initial value: 0.2

Unit: ratio

Variable: **wages-low-skilled-labour**

Description: yearly salary per low-skilled worker in Germany [random]

Initial value: 11

Unit: euros

Variable: **wages-high-skilled-labour**

Description: yearly salary per high-skilled worker in Germany [random]

Initial value: 12

Unit: euros

Variable: **wages-low-skilled-labour-abroad**

Description: yearly salary per low-skilled worker abroad [random]

Initial value: 10

Unit: euros

Variable: **wages-high-skilled-labour-abroad**

Description: yearly salary per high-skilled worker abroad [random]

Initial value: 11

Unit: euros

Variable: **labour-productivity**

Description: amount of output a human worker produces per time step [random]

Initial value: 1

Unit: ratio

Variable: **max-level-of-automation**

Description: maximum level of attainable efficiency of automated production [random]

Initial value: random between 0 and <1

Unit: ratio

Variable: **level-of-automation**

Description: current level of efficiency of automated production [random]

Initial value: random between 0 and <max-level-of-automation

Unit: ratio

Variable: **share-of-automated-firms**

Description: percentage of firms which initially utilised robots for production (Jäger *et al.,* 2016)

Initial value: 29 %

Unit: percentage

Variable: **robot-costs**

Description: costs for maintaining and running robotic automation (e.g. energy bill) [random]

Initial value: 20

Unit: euros

Variable: **robot-productivity**

Description: amount of output a robot produces per time step [random]

Initial value: 10

Unit: ratio

Variable: **robots-kill-jobs-threshold**

Description: technological threshold at which robots eliminate all low-skilled jobs [random]

Initial value: 0.8

Unit: ratio

Variable: **sales-price-per-product**

Description: global sales price for finished products [random]

Initial value: 20

Unit: euros

Variable: **share-for-r&d-investment**

			Description: percentage of revenue allocated for R&D investment [random] Initial value: 1 % Unit: percentage Variable: **share-for-foreign-surcharges** Description: percentage of revenue which is additionally required if production is offshored (e.g. shipping costs or import tariffs) [random] Initial value: 1 % Unit: percentage Variable: **share-for-relocation-costs** Description: percentage of profit required in case of relocation [random] Initial value: 1 % Unit: percentage Variable: **reshored?** Description: label reporting whether production has been reshored or not [path-dependent] Initial value: true or false Unit: label
		III.iv.c How were submodels designed or chosen, and how were they parameterised and then tested?	Parameterisation: The timely order of the submodels initially follows an intuitive order of setting up the economy, industry, and firms first. Further, the production location of the firms is determined. Zooming in on the firm-specific set-up, the individual firms are equipped with a seed capital and a firm's own technological state of the art. These two randomised initial values in combination with defined global parameters result in the aggregation of all other path-dependent submodels. This includes the technological-progress, costs-calculation, human-vs-robot, employment, output-calculation, revenue-calculation, r&d-calculation, profit-calculation, location-decision, firm-size-ratio, and bankruptcy. The parameterisation of

			production, sales, and financial calculation processes follow microeconomic textbook examples (Perloff 2016). During calibration, values of different parameters were adjusted at random aiming at the behaviour of the model to replicate the desired phenomenon, namely the ability of firms to relocate production freely. <u>Testing and validation:</u> In order to validate the created model, the values of the initial setting were controlled whilst testing a minimum and maximum range of values for a selected number of variables. The selection was guided by the reasoning to obtain results which mimick economic dynamics as they can be observed in the real-world which is useful for verifying the functionality of the model.

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