Policies to reconnect a city and the countryside: ODD of an agent-based simulation

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1 Introduction

This document describes an agent-based simulation following the ODD protocol [3] and the data used for calibration, and presents sensitivity analysis results[1].

The agent-based model was created in the context of a project reported by Termeer et al. [9] exploring spatio-temporal dynamics of the economy at the level of the Dutch province Noord-Brabant [7], in particular the south-eastern part of the province. After 1945, Noord-Brabant has been subject to an active program of economic development through the stimulation of pig husbandry. The policy had far-reaching effects on its economy, landscape, environment, and public health, and caused a disconnect between the countryside and urban regions in the south-east where rapidly developing high-tech industries take over the role of main driver of the economy (regional economic growth in 2017: 4.9%).

The simulation supports regional policy making with respect to the relation between city and countryside, in a democratic polity. It enables the exploration of potential consequences of alternative interventions, and counterfactuals, i.e., situations that could have emerged under different courses of events. The simulation is at institutional level, with typical stakeholder groups, lobbies, and political parties playing a role in determining economic and spatial policies.

As an example a region is simulated where the expanding high-tech industry in the city and the intensive livestock industry in the compete for space for housing, farming, and leisure. Tensions arise between the traditionally powerful agricultural sector and environmental, public health, and animal-welfare movements and the high-tech industry. The latter require clean production locations and a healthy, safe, attractive, environment for housing and recreation in order to recruit and sustain highly qualified staff. Public administration is under pressure from environmental, animal welfare, and public health organizations, and from the high-tech industry, to reduce the impact of the livestock industry on the region.

In the sections that follow, the model and the data used for calibration are described, followed by a sensitivity analysis and a discussion on applicability and limitations.

[1] Some background information and a shorter version of the ODD are included in a paper presented in the Social Simulation Conference 2019 [10].

2 ODD of the agent-besed simulation

This section describes the simulation, following the revised ODD protocol [3]. The simulation is programmed in NetLogo [12]; source code is available from the CoMSES OpenABM model library [11] under the title "Policies to reconnect a city and the countryside".

2.1 Purpose

The purpose of the simulation is to make clear how regional policies and material, monetary, migration, and information flows can affect each other under pressure from lobbies, public opinion, and national and EU-policies, in a region where urban high-tech industry and rural intensive livestock industry compete for resources in a democratic polity.

2.2 Entities, state variables, and scales

Fig. 1 depicts the entities represented in the simulation. Several types of agents act in an environment comprising plots with different types of land use. Three sets of plots represent urban, countryside, and village areas. One of the urban plots represents the city center, where offices are located. The other plots can be used for housing or farming. Maximal population density and cost of living depend on the land use type. An urban plot can typically house up to 25 individual households, a village 10, and a countryside plot only one. The countryside typically has the highest cost of living; villages are the cheapest. Livestock keeping can be restricted to particular areas in the countryside. Furthermore, the air around livestock farms can be polluted and health hazards may be effective in case of disease outbreaks.

Households are the main actors in the simulation, where a household stands for an individual with some economic activity and the household depending on that activity. Households are assumed to have a single economic activity or inactivity. They may either be farmers or workers in the agri-industry, or high-tech workers, or be unemployed or disabled. The economic activity generates incoming and outgoing monetary flows, resulting in a cash balance. A farmers' income results from exploitation of a production capacity; the others receive a salary or some form of support. Farmers generate flows of manure, bad air, and, in case of disease outbreaks, infection risk. Other individuals can be affected by these flows. Some country dwellers in financial trouble engage (irreversibly) in criminal activities, such as growing Indian hemp or facilitating drug-labs.

Individuals' actions are assumed to be governed by norms that depend on reference group memberships (Table 1). A reference group is here defined as a group who are expected to act according to a set of common rules (norms). Membership of some reference groups can be chosen by individuals if the norms correspond with their opinions, some can be left if the norms no longer correspond. Membership of some groups is forced by circumstances, such as unemployed and disabled. Membership can be bound by conditions for joining, leaving, or remaining; for

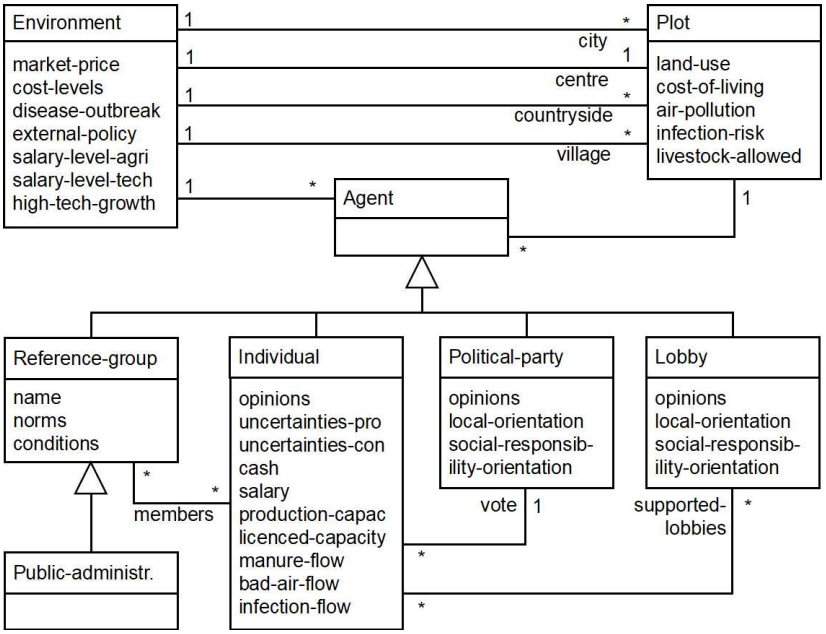

Fig. 1. Class diagram representing the entities in the simulation

instance a farmer has to leave the reference group farmers when bankrupt. Some groups are mutually exclusive, such as farmers and unemployed. Public administration serves as a reference group of which all individuals are members. Its norms apply to all individuals. Emigration is the only way to escape from it.

Political parties and lobbies participate in the formulation of norms to be applied by the public administration, such as conditions for farming licences. Individuals vote for political parties in periodic elections. An individual's vote is assumed to be based on the distance between its opinions vector and those of the parties (the "party programs"). Public administration implements the norms for which a sufficiently positive opinion exists among the parties, weighed by the number of votes. Between elections, party programs may change. Parties are characterized by two dimensions: an orientation towards local problems versus global problems, and an orientation towards economic issues versus social responsibility issues. Lobbies (see Table 1) try and affect the party programs. Their success is assumed to depend on the extent to which their orientations match and on the economic relevance of their supporters, which is measured as the sum of salaries plus farmers' cash flows of individuals.

Furthermore, lobbies try and affect the public opinion. The simulation applies mechanisms of opinion dynamics [4]. The opinions concern norms (see Table 1 for a list of currently implemented norms). Opinions express a positive or negative stance regarding a particular norm, which can be affected by communications from lobbies or discussions with other reference group members. The extent

Table 1. Norms and reference groups currently represented in the simulation

norm	reference groups maintaining the norm
0 invest in livestock farming	farmers
1 care for the local environment	locally involved citizens
2 care for the global environment	globally involved citizens
3 foster agri sector	farmers, agri workers
4 foster high-tech industry	high-tech workers
5 work in agri industry	agri workers
6 work in high-tech industry	high-tech workers
7 live in the countryside	farmers, countryside criminals, commuters
8 live in a village	villagers
9 live in the city	urbanites
10 licence required for livestock	public administration[a]
11 no livestock near populated areas	public administration[a]
12 freeze production capacity	public administration[a]
13 no more licences	public administration[a]
14 engage in criminal activities	countryside criminals
15 don't work	unemployed, patients

[a] policy, only if sufficiently supported by political parties

to which an opinion can be affected depends on an individual's uncertainty about the issue. Uncertainty may be aroused by information flows and events like disease outbreaks. These mechanisms are further discussed under "Submodels". With respect to lobbies, it must be noted that they have another role than the reference groups: reference groups set norms for their members; lobbies try and set norms for others.

The simulation proceeds in an abstract world of 33 by 33 patches, with initially mostly countryside patches where farmers dwell and produce pigs, a village area inhabited by agri-industry workers, and a city populated by workers in the high-tech industry. The industries are assumed to not only comprise the core activities, but also input supply, processing, transport, and services such as finance, accounting, veterinary, construction, maintenance, legal, catering, etc. The simulation typically spans a period of fifty years, in time steps of one year.

2.3 Process overview and scheduling

The simulation starts with initialization by assigning plots to city, countryside, and village areas, and populating the plots: reference groups, lobbies, political parties, and public administration in the city center, high-tech workers in the other city plots, farmers in the countryside, and agri-workers in the village areas. Then the simulation runs for a number of time steps, each representing a year. Fig. 2 depicts the process flow per step.

External influences are generated: the market price for fattened pigs is generated at random between a lower and upper bound set in the user interface. The production cost is increased by a percentage due to national and interna-

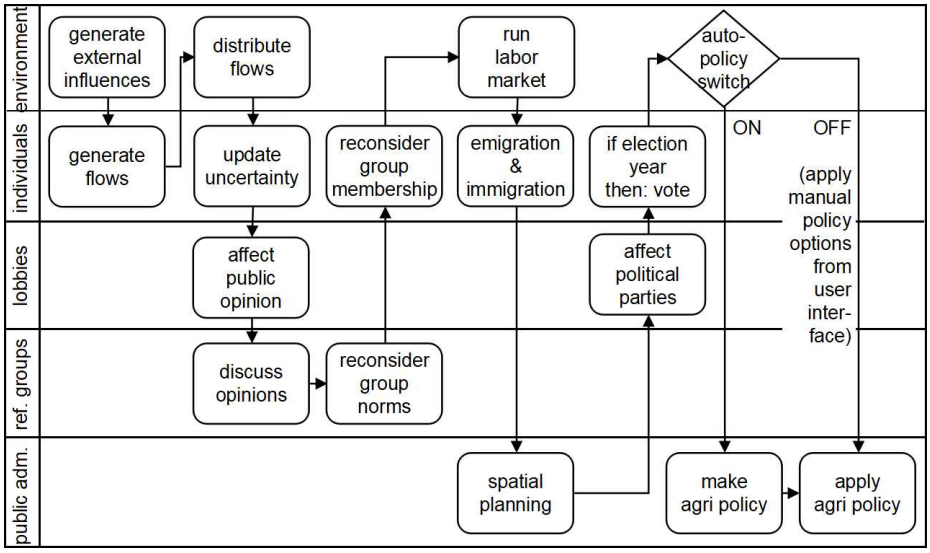

Fig. 2. Process flow in a single, one year, time step

tional environmental and animal welfare policies and quality restrictions. Disease outbreaks are generated with a frequency set in the user interface.

Individuals generate flows. They spend a particular cost of living, depending on the type of plot they live on. Farmers produce pigs, manure, bad air, and infection risks (the latter in case of a disease outbreak), and sell pigs. When they have sufficient capital and licences, they invest in capacity extension. If they have capital but no licence, they apply for it. Workers in high-tech and agri industry receive a salary. Unemployed and patients receive support for the cost of living. Some farmers complete their incomes by facilitating criminal activities.

Flows are distributed through the environment. Manure is accumulated in the environment. Bad air and infection risk spread locally and can cause serious nuisance or disable people. Data on economic growth, population, production, employment, environment, and disease outbreaks become available to all agents.

Flows and aspects of their current situation can affect individuals' uncertainties about their current opinions. For instance, for a farmer a high profit is desirable, but great manure flows may reinforce others' doubts about farming. Bad air may make people uncertain whether they are living in the right place or not. Disease outbreaks may make the public opinion susceptible to campaigns to restrict farming.

Lobbies try and affect the public opinion through communication campaigns, addressing particular uncertainties. Individuals discuss opinions in their reference groups, which generally leads to convergence of opinions. As a result of opinion shifts, a group's norms may be adapted.

Individuals may reconsider their reference group memberships and leave or join groups. These decisions are governed by opinions about the norms, and

by membership conditions. Some changes are voluntary; for instance, high-tech workers who want to live in the countryside can leave the urbanites and join the commuters, if they have sufficient capital and a plot is available. They can move back if they don't like it anymore. Changes can also be forced, e.g., farmers who no longer have sufficient cash or licences must quit, sell their farm, become villagers or urbanites, and join the unemployed.

In the labor market, employment in the agri-industry depends on total pig production in the region; employment in the high-tech industry is assumed to depend on an externally determined growth, which is generated at random within some bounds in each time step. Tight conditions in the labor market induce immigration. On the other hand, long-term unemployment stimulates individuals to emigrate from the region.

Public administration can extend city and village areas in case of population growth. To this end, country dwellers on the edges are expropriated. Depending on current agricultural policy, new licences may granted to expropriated farmers, or they may just be bought out.

Lobbies try and affect political parties' opinions, which are voiced in the party programs. Lobbies can affect policy not only through affecting public opinion before elections. Lobbying continues between election years. The policies implemented by public administration depend on the parties' opinions, weighed by the votes from the recent election. When the parties' opinions change under the influence of lobbies, new policies can be implemented.

Examples of policies directed to livestock farming are investment support (to increase livestock production) and binding livestock keeping by licensing (to achieve the opposite). Licensing enables freezing the total production capacity in the region, reducing total livestock by restricted licensing and buy-out, or restricting livestock farming to particular areas, or combinations of these policies.

2.4 Design concepts

Basic principles of the model are opinion dynamics [4] and rule-following decision-making [6] by individuals and a public administration under a democratic polity, which can constrain farmers' decisions through licensing and buy-out. Land use planning by the public administration prioritizes other industries and housing over agricultural land use and expropriates country dwellers when space is required. The modeled entities and processes are based on historical research on the region and expert data on current politics.

Emergence Potentially emerging phenomena are the growth or collapse of economic sectors, urbanization, pressure on the environment, public support for particular policies, consequences of policies, and the effects from lobbies and arousing events on policies.

Adaptation Individuals may adapt their opinions and change their reference group memberships, and their support for lobbies and political parties. Public policy may change under pressure from lobbies and public opinion.

Objectives The only actors pursuing objectives are the lobbies. Other actors are affected by them, but are modeled as rule-following decision makers.

Learning Based on experience and information, individuals can (based on changed opinions or forced by circumstances) change their reference group memberships and then apply different decision rules. However, they simply follow new rules and do not make or use *Predictions*.

Sensing Individuals can sense the condition of their environment, can receive information flows reporting on consequences of others' actions, and are aware of others' opinions.

Interaction Interactions between individuals in reference groups, between lobbies and individuals and between lobbies and political parties are based on opinion dynamics [4]. Individuals' uncertainty (susceptibility to others' opinions) depends on personal experience, uncertainty arousing events, and information on developments in their environment.

Stochasticity Variation of simulation outcomes results from random fluctuations in pig price, high-tech industry growth, disease outbreaks and, to a lesser extent, randomly generated expropriation decisions, encounters during opinion exchange, opportunities to move, and the distribution of initialized agent traits (production capacity, salary).

Collectives Agents are members of reference groups, in which they maintain common norms and discuss opinions.

Observation The main question is: will the intensive livestock industry collapse or survive? Main observables in this respect are the number of farms, total annual pig production, and employment in the livestock complex. An additional question is: if the livestock sector survives, is that possible without hindering the evolution of the high-tech industry? Observables for this purpose are high-tech employment and emigration of high-tech staff. Furthermore, it is useful to observe the strengths of the different lobbies, general indicators such as population growth and employment, and urbanization (see Fig. 3; the red area is the city).

2.5 Initialization and input data

The simulation is initialized as a world of 33 by 33 patches. Reference groups, lobbies, political parties, and public administration are located on the central patch (see Fig. 3). Around the patch a city is populated with 25 households of high-tech workers per patch, with a salary generated at random around the average, set in the user interface. The countryside is populated with one farm

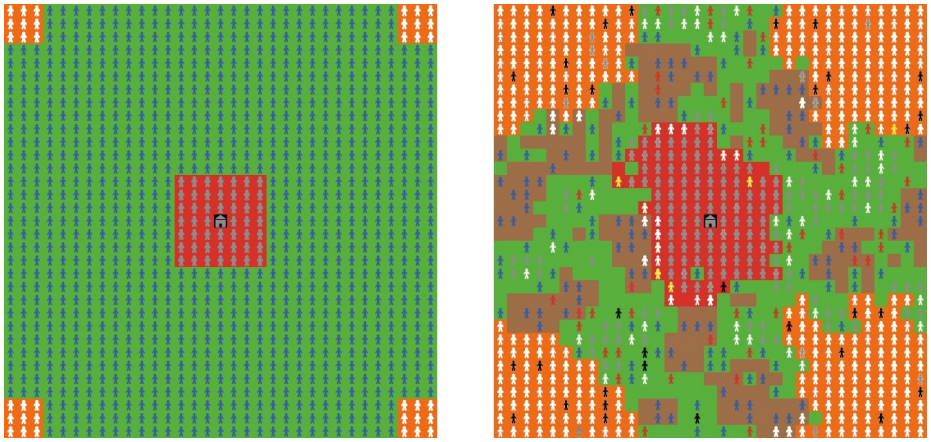

Fig. 3. Examples of the simulated world view, after initialization and a (counterfactual) situation 50 years later, illustrating the effect of urbanization (area color legend: green - countryside; red - city; orange - village; brown - high pressure on the environment)

household per patch, with a production capacity generated at random around the average, set in the user interface. Village areas are populated with 10 agri-sector workers per patch, with a salary generated at random around the average, set in the user interface.

Further inputs and parameters (see Table 2) can be set in the user interface. The inputs are calibrated against data obtained from statistics and experts on the pig husbandry (see Section 3).

Table 2. Inputs and other parameters with their default settings

Parameter	Value	Unit	Parameter	Value	Unit
simulation-time	50	y	country-cost-of-living	30000	/y
mean-initial-capacity	500	pigs/y	city-cost-of-living	25000	/y
price-upper-bound	130	/pig	village-cost-of-living	20000	/y
price-lower-bound	110	/pig	farm-estate-value	1000000	
initial-production-cos	70	/pig	opinion-dynamics-mu	0.2	
external-policy-effect	0.042	/y	initial-uncertainty-min	0.4	
capacity-investment-cost	200		initial-uncertainty-max	0.6	
outbreak-frequency	0.04	/y	interaction-partners	2	/y
criminal-susceptibility	0		norm-adoption-threshold	0.83	
mean-salary-agri	40000	/y	policy-threshold	0.5	
agri-complex-employment	0.001	/pig/y	lobby-effectiveness	0.3	
mean-salary-tech	30000	/y	election-period	4	y
tech-industry-growth	3.3	%/y	unemployed-emigration-factor	0.1	/y
bad-air-limit	30000	pigs/y			

2.6 Submodels

This subsection describes the implementation of the processes represented in Fig. 2.

generate external influences The current farmgate price $p_f(t)$ per pig is in each time step set to a new random value drawn from the uniform distribution on the interval $[p_l, p_u]$, i.e. between lower and upper price bounds from Table 2.

Current production cost is set to $c_p(t) = (1+\phi)c_p(t-1)$, where ϕ represents the external policy effect and $c_p(-1)$ is the initial production cost from Table 2.

Whether or not a disease will break out in the current time step is a Bernoulli variable with probability equal to the outbreak frequency from Table 2. In case of an outbreak, the infection strength s_i is, for now, set equal to the outbreak frequency.

generate flows Flows are generated by individuals, who behave according to norms. The rules which the individuals follow are based on the norms of reference groups to which they belong.

norm 0 "invest in livestock farming" Farmers are assumed to produce pigs with their full production capacity q_p. Their cash balance is updated as

$$b_c(t) = b_c(t-1) + q_p(p_f(t) - c_p(t)). \tag{1}$$

The production causes outgoing flows of manure and local bad air, proportional to q_p. In case of a disease outbreak, the probability of being infected is, for now, set equal to the outbreak frequency, and production and revenue are assumed zero for the current time step, while cost remains the full production cost. In case of an infection, the farm is assumed to cause an outgoing flow of local infection risk equal to s_i.

Since farmers are known to prefer investment in scale enlargement [1], they are assumed to invest as much as possible of the surplus of their revenue minus production cost and cost of living in additional production capacity, if not prohibited by policies and their licence is sufficient. In case of investment, the cost is subtracted from their cash balance and the production capacity is accordingly increased. Cost of capacity extension per pig/year is specified as a parameter (Table 2).

norm 1 "care for the local environment" Support the local resonsibility lobby, with a weight according to income.

norm 2 "care for the global environment" Support the global resonsibility lobby, with a weight according to income.

norm 3 "foster agri sector" Support the livestock lobby, with a weight according to income.

norm 4 "foster high-tech industry" Support high-tech lobby, with a weight according to income.

norm 5 "work in agri industry" Increase cash balance with salary.

norm 6 "work in high-tech industry" Increase cash balance with salary.

norm 7 "live in the countryside" Decrease cash balance by cost of living of the current place.

norm 8 "live in a village" Decrease cash balance by cost of living of the current place.

norm 9 "live in the city" Decrease cash balance by cost of living of the current place.

norm 10 "licence required for livestock" A farmer must apply for a licence if the current production capacity q_p is greater than the licensed capacity q_l or when the farmer has a sufficient cash balance to invest in capacity extension and the current licence is not sufficient. This norm causes a delay of one time step in investments. The farmer requests an (additional) licence for production capacity

$$q_l(t+1) = q_p(t) - q_l(t) + \max\{0, c_i b_c(t)\}, \tag{2}$$

where c_i stands for the investment cost from Table 2. If the licence is granted, the farmer's licensed capacity is updated by the public administration agent.

norm 11 "no livestock near populated areas" A farmer must quit farming if the farm is located in a zone where livestock farming is not allowed. The farmer is bought out: cash balance is increased with the investment cost of the production capacity and production capacity is set equal to zero. The farmer must find another occupation, but receives a production licence to start a new farm in a zone where it is permitted, unless norm 13 is in place.

norm 12 "freeze production capacity" Licences are granted only if the total production capacity in the region does not exceed upper bound and the farmer is not located in a no-livestock zone.

norm 13 "no more licences" No new licences are granted.

norm 14 "engage in criminal activities" Farmers in crime are assumed to supplement their income up to the cost of living in the countryside.

norm 15 "don't work" Unemployed and patients receive income support for the cost of living, maximized by the cost of living in the city.

distribute flows Effects of flows are aggregated:

- annual pig production, annual manure production, current mean production capacity of farms
- local environmental conditions, based on total production capacity on the patch and its neighbors; patches affected by a production capacity of more than the bad air limit parameter (see Table 2) are colored brown
- infection probability per patch, computed as the sum of infection flows on the patch and its neighbors; patches with infection risk > 0 are colored pink
- human infections: individuals on pink patches are infected with probability as calculated
- local human disease prevalence: presence of disabled persons (patients) on the patch or, if in the countryside, its neighbors
- the current set of not inhabited countryside patches is determined, ready to be repopulated by bought-out farmers or sufficiently rich other individuals
- relative lobby strengths are calculated as current support divided by the support the lobby would have if all individuals would support it

update uncertainty Individuals have opinions on the norms of their own reference groups and those of other groups. Opinions on norms are represented as a vector $\boldsymbol{x}$; each element x_i represents an opinion on a particular norm n_i as a real number on a scale from 0 (negative opinion) to 1 (positive opinion). Individual's opinions are initialized as $x_i = 1$ for the norms of their reference groups, $x_i = 0.5$ (indifferent) for other norms.

Table 3. Triggers that are assumed to arouse individuals' susceptibility to negative information about norms (y) or to positive information (z)

trigger	norms															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
– farmers:																
have pig production capacity	z	y	y	z							y	y	y	y	y	y
– others:																
receive salary from agri industry				z		z		z	z					y	y	y
receive salary from tech industry		z			z	z		z		z		z			y	y
be unemployed				z	z	z	z								y	
be aware of rapid farm size growth[a]	y		z	y							z		z	z		
experience bad air in neighbourhood	y	z		y		z		y		y		z				
infections in the neighbourhood	y	z		y						y	z	z	z	z		

[a] does not apply to agri-industry employees

Individuals can be more or less uncertain about their opinions. Uncertainty is expressed as a real value between 0 (absolutely certain; the opinion can not be affected) and 1 (extremely susceptible to information intending to affect the opinion). The uncertainties are represented as vectors $\boldsymbol{y}$ (susceptibility to negative information about norms) and $\boldsymbol{z}$ (susceptibility to positive information).

The uncertainties are initialized to a random value between the bounds set in the user interface (see Table 2). Uncertainties can be aroused by experiences: in case of a negative experience with respect to norm n_i, y_i is set equal to 1 for one time step, in case of a positive experience z_i is set to 1. The arousal effects assumed in the simulation are summarized in Table 3. In the next time step the values return to the default, unless another arousing event occurs.

affect public opinion Lobbies do not change their opinions, but affect those of political parties and individuals. Lobbies' opinions are initialized as $x_i = 1$ for the norms they promote, $x_i = 0$ for the norms they oppose, $x_i = 0.5$ for the other norms. Table 4 presents the norms opposed and promoted by the lobbies.

Table 4. Local versus global (λ_l) and responsibility versus economy (ρ_l) orientation, and opinion x_i about norms opposed (0) and promoted (z) by the lobbies; x_i=0.5 for the other norms

trigger	orientation		norms															
	λ_l	ρ_l	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
livestock lobby	1	0	1			1							0	0	0	0		
high-tech lobby	0	0		1			1		1					1			0	
global resp. lobby	0	1	0	1	1	0							1		1	1		1
local resp. lobby	1	1		1									1	1	1		0	1

An individual's opinion can be affected by another agent, such as a lobby, according to the individual's left-hand (y_i) and right-hand (z_i) uncertainties:

$$x_i(t+1) = \begin{cases} x_i(t) + \mu(x'_i(t) - x_i(t)), & \text{if } -y_i \leq x'_i(t) - x_i(t) \leq z_i \\ x_i(t), & \text{otherwise,} \end{cases} \tag{3}$$

where μ is the opinion dynamics convergence parameter, $0 \leq \mu \leq 0.5$ (see Table 2).

discuss opinions Individuals discuss opinions in their reference groups. During a time step they meet a number of fellow group members, selected at random. with which they "discuss" and both update their opinions according to equation 3. The number of interactions per time is set in the user interface (see Table 2).

reconsider group norms Except the public administration, of which the norms are set through the process "make policy", a reference groups adopts a new norm when the average opinion of its members about the norm exceeds the norm adoption threshold τ from Table 2.

A reference group rejects a current norm when the average opinion of its members about the norm is less than $1 - \tau$.

reconsider group memberships Individuals reconsider their reference group memberships in each time step:

- bought-out farmers search for a new farm
- sufficiently rich other individuals try and buy a country plot where environmental conditions are not too bad
- country dwellers in financial trouble on the edges of city and village areas sell their plots to the municipalities; others engage in crime with probability "criminal susceptibility" () or sell their plots and move to villages
- other individuals in financial trouble move from city to village, vice versa, to minimize cost of living
- non-farmer individuals living in areas with bad environmental conditions or where patients of livestock-related diseases live, or neighboring such places, join the reference group "locally involved", i.e., support the local responsibility lobby
- non-farmer individuals who do not work in the agri-industry join the reference-group "globally involved" with a probability proportional to the growth of production capacity
- non-farmer countryside dwellers move to the city when their patch or an adjacent patch is colored brown

run labor market Employment in the agri-complex is assumed to be proportional to pig production, with the factor "agri-complex-employment" (see Table 2). Employment related to the high-tech industry initially equals 1200 emloyees and annually grows with a random percentage between -0.5 and 2.5 times "tech-industry-growth" (see Table 2).

When the current number of employees in either industry exceeds the employment calculated as above, the surplus is laid off. In case of shortage of employees, first unemployed living in the region are recruited and then, in case of remaining shortage, immigrants are recruited.

emigration & immigration Emigration occurs for to reasons. Annually a fraction of the unemployed (unemployed-emigration-factor from Table 2) emigrate to find work outside the region. High-tech workers living on the edge of the city emigrate when environmental conditions in the location where they live become bad (brown colored patches).

Immigrants are recruited in case of shortage in the labor market. Agri-sector workers are housed in the village area, high-tech workers in the city.

spatial planning When additional space in the city or the village area is needed to house immigrants or due to internal migration in the region, random owners of countryside patches on the edge of city or village are expropriated until sufficient space is available. Expropriated land owners receive a financial compensation for the value of the property and investments in production capacity.

affect political parties For political parties, opinions represent the party programs. All opinions are initialized as $x_i = 0.5$ and are affected by affected only by lobbies, depending on the "ideological distance".

The lobbies' effects on opinions in political party programs is computed as:

$$x_i(t+1) = x_i(t) + \epsilon\sigma\delta(x'_i - x_i(t)), \tag{4}$$

where x'_i stands for a lobby's opinion on norm i and lobby effectiveness ϵ is a global parameter (see Table 2); $0 < \epsilon < 1$. A lobby's strength σ is computed as the sum of salaries plus farmers' cash flows of individuals who support the lobby, divided by the sum of salaries plus farmers' cash flows of all individuals. The ideological distance $\delta = (|\lambda_\mathrm{p} - \lambda_\mathrm{l}| + |\rho_\mathrm{p} - \rho_\mathrm{l}|)/2$, where λ_p, λ_l, ρ_p, and ρ_l stand for local versus global and social responsibility versus economy orientations of party and lobby, all as real variables in [0...1].

vote In elections, individuals vote so that they minimize the Manhattan distance between a party's and their own opinion vectors. Then, in the "make policy" process, policies are installed or changed according to the weighted average opinion of parties.

make policy The public administration agent aggregates the political parties' opinions, weighted by the votes from the most recent election and updates the policies (norms 10, 11, 12, and 13).

When the auto-policy switch is ON, the agent updates the norms n_i in time step t according to the parties' weighted opinions $\omega_i(t), i \in \{10, 11, 12, 13\}$, taking the policy threshold θ from Table 2 into account: n_i is put in place in time step t if n_i was not in effect in $t-1$ and $\omega_i(t) > \theta$; once in place, a policy is not reversible.

When the auto-policy switch is OFF, the agent sets the norms according to the switches in the user interface.

Norm 10 "licence required for livestock" is automatically enforced when another policy is in place.

apply policy When norm 11 "no livestock near populated areas" is in place, the variable "livestock-allowed" of patches with Manhattan distance < 3 is set true, and the patches that are not "brown" are colored "lime". Farmers on these patches will be bought out in the *generate flows* process and no new licences are granted for these patches; "livestock-allowed" is set true for the country side and countryside patches that are not "brown" are colored "green" when norm 11 is not in place.

When norm 12 "freeze production capacity" is in place, the total licensed capacity is limited to the total installed production capacity at the moment the policy came into effect. No licences will be granted when the frozen capacity limit is exceeded. Only when other farms quit, farmers can get new or additional production licences.

When norm 13 "no more licences" is in place, no new or additional production licences will be granted at all.

When norm 10 "licence required for livestock" is the only policy in place, all licence requests will be honored, with a delay of one time step.

3 Data

In this section, the data is described that underlie the default parameter values presented in Table 2. In many cases, no detailed statistical data is available at the regional level or for specific sectors. Then data from higher levels of aggregation or an expert estimate or a combination is used, or an assumption is made. Where assumptions are made, the parameters are included in the sensitivity analysis, reported in Section 4.

3.1 Data on south-eastern Noord-Brabant

Fig. 4 depicts a map of Dutch economic regions, with a pointer to south-eastern Noord-Brabant, where economic growth amounted to 4.9% in 2017.

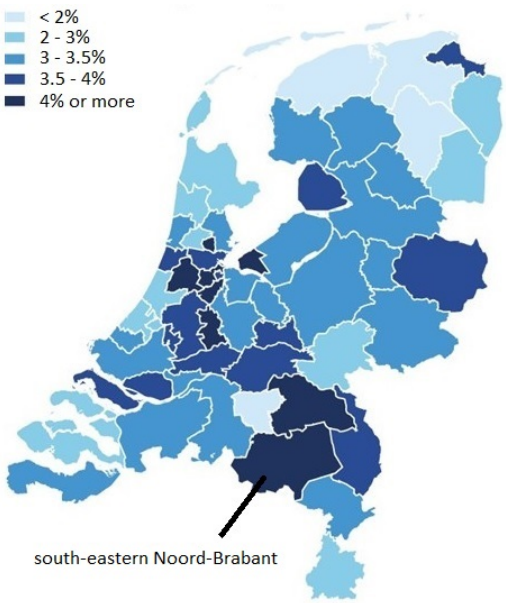

Fig. 4. Economic growth of Dutch regions in 2017 (source: Central Bureau of Statistics)

Table 5 shows that urbanization is continuing, the number of housing units is growing more rapidly than the population. In 2015 – 2018, steadily about 2.4

million pigs were kept in the region; that is about 20% of all pigs kept in the Netherlands and 40% of pigs kept in the province of Noord-Brabant.

Table 5. Population, urbanisation, housing, and number of pigs in south-eastern Noord-Brabant (source: Central Bureau of Statistics)

year	population (/1000)	living in urban areas (%)	number of housing units (/1000)	number of pigs (/1000)	comment
2000	709.4	52.9	285.7	2265	
2019	773.2	63.1	345.9	2394	(number of pigs in 2018)

Employment is the region is mainly in services. The recent employment in production industry, mainly high-tech, is presented in Table 6. The average annual growth amounts to 3.3% (arithmatic mean).

Table 6. Number of jobs in production industry in south-eastern Noord-Brabant in recent years (source: Central Bureau of Statistics)

year	number of jobs (/1000)
2014	44.4
2015	44.4
2016	46.4
2017	49.0

3.2 Data on pig husbandry

Table 7 displays the development of pig husbandry and pork production in the Netherlands in second half of the twentieth century. The Table shows the effects of specialization and a rapid growth of production capacity, which reached its maximum in the nineties. Further growth was then restricted by government policy.

From 1975 onward, the number of pigs has been surveyed in the annual agricultural census. Fig. 5 depicts data for the Netherlands. The first national policy interventions, slowing down the growth, occurred in the nineteen-eighties. and a growing share of the total pig stock. The figure also shows the concentration of pig husbandry in Noord-Brabant, with larger farms.

Over the years 1975-2017 the number of farms keeping pigs in the Netherlands decreased from 55220 (of which 11846 in Noord-Brabant) to 4301 (of which 1574 in Noord-Brabant), as shown in Fig. 6. As mentioned in the previous subsection, about 2.4 million pigs were kept in south-eastern Noord-Brabant in 2015 – 2018.

Table 7. Number of farms and pork production in the Netherlands over the years 1950–2000 (source: Central Bureau of Statistics)

year	number of farms (/1000)	farms keeping pigs (/1000)	pork production (1000 ton)
1950	410	271	236
1960	301	146	413
1970	185	76	700
1980	155	42	1125
1990	125	28	1662
2000	97	15	1623

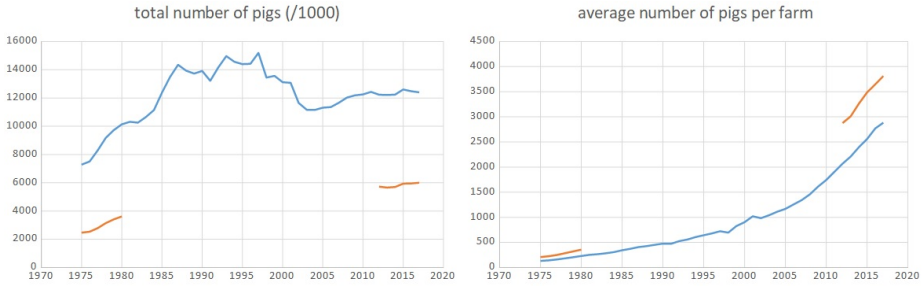

Fig. 5. Total number of pigs and pigs per pig farm in 1975 – 2017 in the Netherlands (blue) and, for the beginning and end of the period, for Noord-Brabant (red)

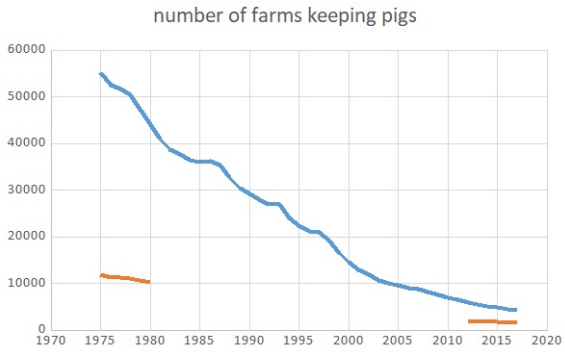

Fig. 6. Number of farms keeping pigs in the Netherlands (blue) and Noord-Brabant (red) in 1975 – 2017 (source: Central Bureau of Statistics)

Farm size is rapidly increasing, while the number of farms keeps decreasing. As can be seen in Table 8, the share of debt capital is also increasing. Based on the added value reported this table, the default value for production cost in the beginning of the simulation is set to 75% of the average farmgate price.

Table 8. Averaged financial indicators for pig faming in The Netherlands (NL) and Noord-Brabant (N-B) (source: Wageningen UR, farm accountancy data network)

Indicator	1975 – 1979		2012 – 2016	
	NL	N-B	NL	N-B
annual farmer's added value[a] (euro/y)	25120	29923	46018	51891
ratio farmer's added value/total cost	0.226	0.255	0.060	0.060
ratio fixed cost/total cost	0.154	0.142	0.230	0.222
ratio debt capital/total capital	0.248	0.217	0.517	0.576
private capital (1000 euro)	210	242	1122	1170

[a] total added value minus cost of debt capital and hired labor

Market and government and policies require ever more investments to improve quality and animal welfare, and to reduce environmental effects and health risks. As a consequence, the fixed cost ratio is increased. Under competition in the European market, farmers' margins (added value) are decreasing. The decline of farmers' added value/total cost ratio corresponds with an arithmetic mean annual reduction of the net margin per pig by 3.7%.

Farmers must chose between investments in cost reduction and capacity upscaling, switching to niche markets with higher margins, and quitting pig husbandry. Recent research concluded that they prefer to invest in cost-price reduction through modernization and scale enlargement [1].

The smaller margins lead to increased variations of farmers' incomes due to price fluctuations, as can be seen in Fig. 7. Fig. 8 shows that market price fluctuations have not changed so much over 40 years.

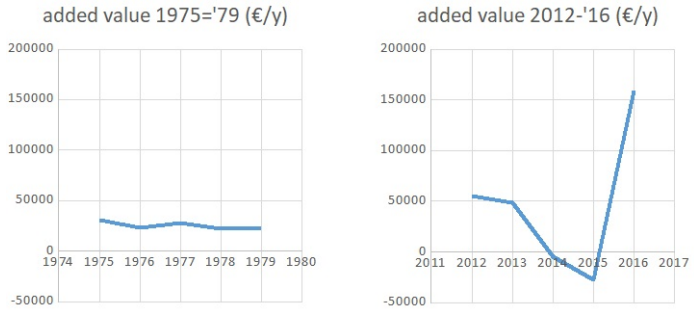

Fig. 7. Average farmers' added values (total added value minus paid interests and hired labor) (source: Wageningen UR, farm accountancy data network)

3.3 Data on pig price

According to experts, the price is mainly depending on the European market, with some effect of the world market, in particular since the Chinese arket was opened in 2016. In the period from 1975 to 2000, prices gradually decreased, as a result of competition in European markets and, initially, production stimulating policies, later on increasing production efficiency and decreasing feed price. Since 2000, prices go up as consequence of increasing feed price and demands for quality, animal welfare, and environmental impact reduction.

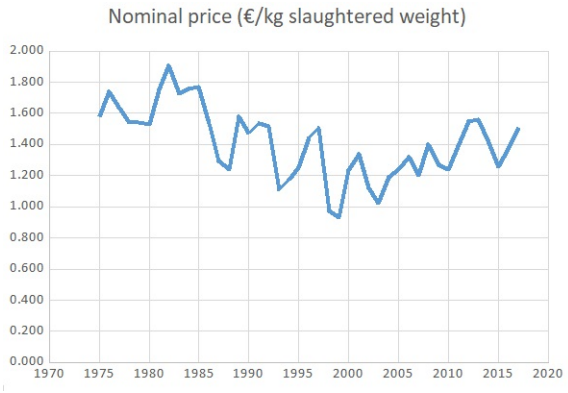

Fig. 8. Annual averaged farmgate price (source: Wageningen UR, price information desk)

The price per delivered pig can be estimated from the data presented in Table 9. Based on this information and the data in Fig figure:Price.

3.4 Other data

Data reported above can be used for parameter setting and comparing the evolution of number of farms, number of pigs, employment growth, and urbanization with actual historical evolution. Other data are assumed and can, in part, be used to calibrate the historical evolution.

Salaries in the livestock complex are by default set lower than the livestock salaries. cost of living in the city is set higher than cost of living in a village. Agri-complex employees are initially housed in the village, high-tech employees in the city. Cost of living in the countryside is by default set to a higher value; it is assumed to include the maintenance of the estate and commuting. Farm estate value is set to an assumed value in the realistic range of current prices.

Parameters for opinion dynamics, threshold-values for norm adoption, lobby effectiveness, emigration, disease impact, and criminal susceptibility are assumed and are subject to sensitivity analysis for calibration.

Table 9. Price per pig, based on average price per kg and average slaughtered (source for slaugtered weight: CBS statline)

year	price (euro/kg)	average weight (kg)	value[a] (euro/pig)
1990	1.47	83.32	123
1995	1.25	87.14	109
2000	1.23	87.42	108
2005	1.24	90.23	112
2006	1.32	90.18	119
2007	1.20	90.92	109
2008	1.40	90.84	127
2009	1.27	92.29	117
2014	1.41	93.92	132
2015	1.26	94.04	118
2017	1.51	95.96	145

[a] average value: 120 euro/pig

4 Sensitivity analysis

The sensitivity analysis is performed in two steps. First, with regional politics switched off, to test the parameter settings for the pig production processes. Then, with regional politics, to test sensitivity for the parameters of the opinion dynamics and the political processes.

4.1 Pig husbandry

Parameter settings for pig production are based on the data presented in the previous section. The farmgate price is set to vary at random between 110 and 130, average 120 during each of the simulations. Table 10 presents the default parameters for the base scenario and the settings used in the sensitivity analysis[2]. Other parameters are set as in Table 2.

Table 11 presents average outcomes from 32 runs with default parameter settings. The outcomes match with estimates based on data presented in the previous section. Fig. 9 depicts outcomes from a default run, where no regional policies are applied to regulate livestock farming. The increasing income fluctuations match with Fig. 7.

The sensitivity analysis was performed on 32 runs with each possible combination of the low and high values from Table 10, plus the 32 runs with default parameters. Based on the simulation results, linear models were estimated for the number of farms, total annual pig production, and average farm income. All

[2] The average external policy effect according to the data was 3.7% per year and the initial input cost 90, but in the beginning of the simulation period no external policies were in place and the effect was stronger in the end of the period. Therefore, the setting for external policy effect is raised with set 0.5%. Intitial input cost is lowered to 70 to compensate for this change.

Table 10. Pig husbandry parameters applied in base scenario and sensitivity analysis

parameter	default value	SA value low	SA value high
mean-initial-capacity	500	450	550
initial-production-cost	70	65	75
external-policy-effect	0.042	0.037	0.047
capacity-investment-cost	200	180	220
country-cost-of-living	30000	27000	33000

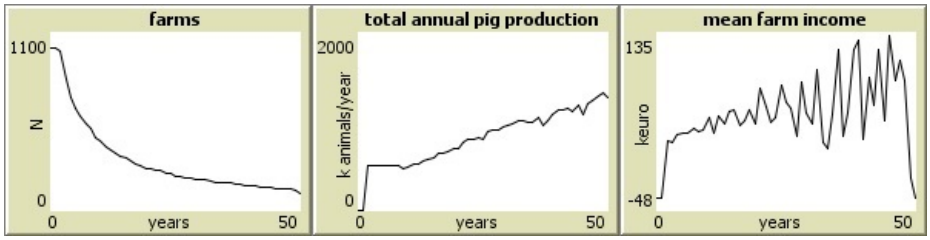

Fig. 9. Example of simulation outcomes with default parameters, without local politics

parameters proved significant, but the extent of their contributions to the variation in outcomes was different. The results show great variation due to price fluctuations and other stochastic effects, e.g. disease outbreaks, and the phase of the simulation where such fluctuations occur. Table 11 presents the contributions of stochastics (ratio: average in-sample variance / total variance) and parameters first-order contributions of parameters to variance [8]. The table shows that production cost and external policy effects are the main drivers of variation in simulation outcomes.

Table 11. Results from default runs and sensitivity analysis of pig husbandry

statistic	number of farms	annual production /1000 pigs	average farm income
estimate of real value according to data	130	1200	52000
– runs with default parameters:			
mean value of 32 runs with base scenario	156	1191	47082
standard deviation of base scenario runs	28	541	55503
– sensitivity analysis:			
variance due to stochastics	24.0%	8.4%	50.3%
– first-order contributions to variance:			
mean-initial-capacity	8.0%	10.7%	3.2%
initial-production-cost	12.7%	36.6%	11.0%
external-policy-effect	1.2%	12.3%	8.9%
capacity-investment-cost	0.7%	9.0%	4.9%
country-cost-of-living	8.0%	8.9%	1.9%

4.2 Opinion dynamics and local politics

The simulation outcomes are sensitive to political interventions. Fig. 10 Depicts a situation evolved without interventions and a situation where livestock keeping is controlled by a licensing system and bought-out near populated areas.

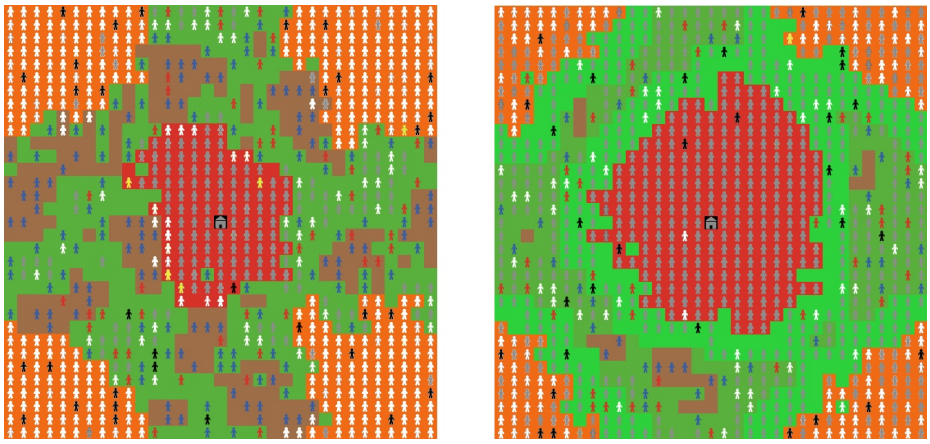

Fig. 10. Examples of situations evolved without political interventions (left-hand side) and a scenario with the politics switched on (right-hand side) (area color legend: green - countryside; red - city; orange - village; brown - high pressure on the environment)

The right-hand side of Fig. 10 depicts a typical situation that evolves with default parameter values (Table 2) and the auto-politics switch set on. To test the sensitivity for the opinion dynamics and other parameters in the political processes, the parameters were tested one-by-one. For each parameter approximately 50 simulations were run, with the parameter varying in small steps through the ranges represented in Table 12.

Table 12. Parameters tested in the sensitivity analysis, with default value and the applied variation

parameter	default	variation
opinion-dynamics-mu	0.20	steps of 0.02 from 0.10 to 0.30
initial-uncertainty-min	0.40	a range of values [0.30 ... 0.49][a]
initial-uncertainty-max	0.60	a range of values [0.51 ... 0.70][a]
interaction-partners	2	{1, 2, 3, 4, 5, 6, 7}
policy-threshold	0.55	steps of 0.02 from 0.50 to 0.72
lobby-effectiveness	0.30	steps 0f 0.02 from 0.20 to 0.50

[a] each value of initial-uncertainty-min was combined with each value of initial-uncertainty-min in the simulations to test for uncertainty

The average value of the total production capacity at the end of the simulation was 859.000 animals/year, a reduction of 28% compared to the value without politics (Table 11). The conclusion is that the system is sensitive to the political interventions. However, none of the parameter variations from Table 12 had a relevant or significant effect on the final outcomes, with one exception: the policy threshold, i.e., the weighted (with votes) average of political parties' opinions required for a policy to be put in place. The effect on the final production capacity is not significant, but the effect on implemented policies is.

Fig. {figure:threshold depicts the frequencies of adopted policies, depending on the policy-threshold. The effect occur with the policies "freeze production capacity" and "no more licences". For the policy "not near the city" pressure is put on the political parties by more lobbies, among which the powerful high-tech lobby, when the environmental situation close by the city becomes bad. The other policies have less powerful supporters and need more time to be accepted.

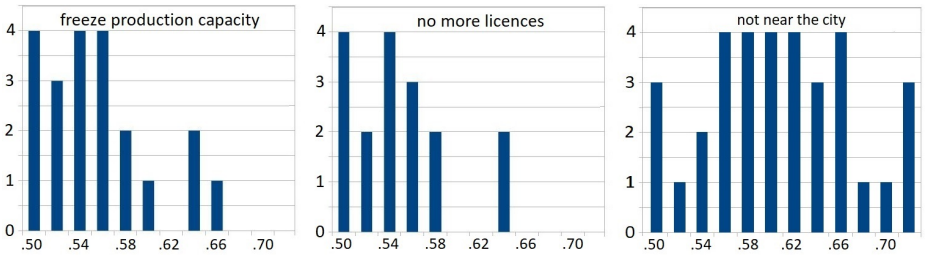

Fig. 11. Frequency of policies being implemented when varying the policy threshold from 0.50 to 0.72 in steps of 0.02, with four simulation runs for each step

5 Discussion

5.1 Model concepts

From an ontological point of view, the ambition of this model is to find a middle ground between, on the one hand, "artificial sociality" models that center on relational processes, and on the other hand, economic models that have simple utility-maximizing agents. We attempted to construct an institutional / political world. We believe that we struck a workable balance between ontological simplicity and plausibility. The combined use of reference groups, lobbies and political parties has potential and can serve as a canvas for other simulations. The model would allow for improvements on the "artificial sociality" side, for instance, by varying the strength of certain reference groups, or by basing voting behavior more on reference group membership and less on opinions.

The relative insensitivity for variation of opinion dynamics dynamics parameters can be explained: the work from both sides, for forces pro as well as forces against particular norms.

A weakness of the model is the focus on a single issue, while in real politics concern a range of issues. In the voting behavior of the citizens and the formation of coalitions in a multi-party polity, under the pressure of multiple lobbies on multiple topics, policies do not necessarily reflect the public opinion. On the other hand, in the long run, the public opinion can prevail.

5.2 Validation

For a model of this kind, validation is a thorny issue. It implements ideas from institutional economics in an eclectic way, since no theory offers clear guidance; the theories were not invented for that purpose. This means that the model cannot be "validated against theory". On the other hand, it is too stylized to exactly represent the province of Noord-Brabant that served as its source of inspiration and calibration. We therefore aim for no more than face validation based on second-order effects in the simulation. Considered from this perspective the model performs well. The actual state of Noord-Brabant is marked by the pressures discussed above, where the disconnected livestock industry prevails, and 10, where the reconnect is being realized through the institutions of a democratic polity.

In line with the above, the purpose of this model cannot be to predict, nor even to closely "backcast" what has already happened. Instead it is an illustration of the main issues driving the economic history of the system. It can serve as a boundary object to inform policy, to be used in imagining various futures for the region. It can be useful, provided it is not used out of context or with too many validity claims [2].

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