Policy Emergence

An agent-based approach - C&F Update

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by

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Contents

1

The Conceptualisation

This chapter presents the entire revised conceptualisation. It was revised after reflection on the actions. The formalisation is similarly revised in the next appendix.

1.1. Common core

The policy emergence process is a process composed of several **iterative stages**. Different iterative stages can be differentiated. There are iterative stages where the **actors** present in the **policy arena** interact with each other. The policy arena is the environment in which these connected actors evolve. Additionally, different types of actors are present within the policy arena. They are the **policy makers**, the **policy entrepreneurs** and the **external parties**. The policy makers are the actors that have decision making power. This means that they can decide what is placed on the **agenda** or what **policy instrument** should be implemented. The former is performed in the round called the **agenda setting** while the latter is perform during the round called the **policy formulation**. They can also work to influence the **beliefs** of the other actors present in the policy arena which are connected to them through their **policy network**. The policy network is the network that connects the actors present in one policy arena. The actors are connected based on their awareness of one another. The likelihood of actors to interact with one another is dependent on their awareness of one another. Over time the policy network of the actors will deteriorate. To maintain their network, the actors are able to perform simple actions using their **resources**. These resources represent their financial and political resources.

Each policy maker possesses a belief hierarchy that defines its beliefs on the issues being discussed in the policy arena. This hierarchy is composed of field wide beliefs at the top and beliefs on increasingly detailed issues when progressing downwards in the hierarchy. Example of issues are public transportation or the amount of plastic present with a size less than 2 millimetres present in the oceans. For each of these issues, the actors have an understanding of the current **states of the world** and a goal for where they would like to see this issue be. Furthermore, each level in the hierarchy is connected to the next through causal relations up to the highest level. These causal relations help the actor understand how different issues affect each other and therefore how the world works.

The impact of the influence of the policy makers on the other actors is dependent on the resources spent by the policy makers, the difference in beliefs they have with the actor they are influencing and the affiliation of both influencing and influenced actor. However,

before influencing other actors, a decision must be made on what influence should be performed and on which actor. The likelihood that a policy maker will influence another actor will vary depending on their **political affiliation** in relation to the affiliation of the actor influenced, their perceived **conflict level** on the issues concerned with the actor influenced, their policy network (awareness level) and whether the actor being influenced is a policy maker or another actor. Within the policy arena, actors will prefer influencing policy makers as they have decision making power (they decide on the agenda and the policy instrument to be implemented). The political affiliation of the actors relates them to specific **constituencies**. Furthermore, it affects the likelihood of actors of different affiliation of interacting with one another. The resources available to the policy makers are dependent on the size of their affiliated constituencies. There is a conflict level for each issue represented in the beliefs of a policy maker. This conflict level is the difference in the views of the world of the policy maker and what the policy maker thinks the beliefs of the actors influenced are. This perception of actor B's beliefs by actor A is referred to as the **partial knowledge** of the actor A. The amount of conflict level will affect the likelihood of the two actors interacting with one another about certain issues. Actors are more likely to discuss issues for which they have a mild conflict level and less likely to discuss issues for which they have a high conflict level.

There are different types of actions which the policy makers can perform on the other actors. They can perform **framing actions**. These actions are attempts to influence other actors on their beliefs of how the world works (the causal relations in their beliefs hierarchies). The policy makers can also **directly influence** the actors on their beliefs for the issues. They can influence them on the way they see the world or on their aims of what the world should be. Because the **attention span** of the actors in the policy arena is limited, these actors tend to only influence other actors on one selected issue. This issue is selected based on the appearance of **urgency**. This urgency is determined by the actors based on the gap between the current states of the world and their aim but also in relation to the impact that this issue ultimately has on their normative beliefs. The ultimate goals of the policy makers being to reach their normative belief goals.

The partial knowledge of the actors is updated whenever an influencing action is performed. Both the actor influencing and the actor being influenced have been part of the interaction and therefore get a better, but not perfect, understanding of each other's beliefs on the topic of the interaction.

As mentioned earlier, the policy makers can also decide what is on the agenda. This is done by selecting the issue that they consider to be the most urgent to them. The issue that is ultimately placed on the agenda is the issue that most policy makers believe is urgent. The choice of issue on the agenda will go on to define which issues can be discussed in iterative stages looking at lower level issues in the belief hierarchies. The issues all have to be related to the issue on the agenda. This is however subjective to the actors depending on their personal beliefs. The process of agenda setting therefore helps narrow down the problems observed by the policy makers and to ultimately decide on a **policy instrument** that can be used to address such problem.

The policy entrepreneurs are actors that seek to influence the beliefs of the policy makers primarily but also to influence the beliefs of the other actors within the policy arena through their policy network. Their aim is to push their beliefs onto the other actors present in the arena. Similarly to the policy makers, the policy entrepreneurs have a belief hierar-

chy, a political affiliation and use resources to influence other actors. These resources are also defined based on their constituencies. They can also perform different actions on the policy makers, external parties and other policy entrepreneurs. They can frame how the world works, influence on the beliefs of other actor's view of the world and their goals. The likelihood of performing an action and its actual impact are determined in a similar way as for the policy makers.

The external parties are actors that have multiple roles within the policy arena. The external parties represent actors such as the media, but also research institute or academic institutions. They help inform other external parties, the policy makers, the policy entrepreneurs about the current state of the world. They can also influence other external parties, policy makers and policy entrepreneurs on their beliefs of how the world works, on issue states and on issue aims. Finally, they can influence the goals of the constituencies. Similarly to the policy makers, the external parties have a certain political affiliation and resources stemming from that affiliation.

The external parties have direct access to the states of the world. They can therefore transmit this information to the actors within the policy arena along with the constituencies. However, not all external parties are interested in all states of the world, some external parties are only interested in specific states. Furthermore, this transmission of the states is dependent on the policy network, and the affiliation of the external parties and the actors to whom they are transmitting this information. Different actors will perceive the external parties as more or less trust worthy depending on their affiliation.

The external parties can also influence other external parties, the policy makers and the policy entrepreneurs. They can do this through framing actions, influence on aim actions and influence on state actions that affect all actors present in the policy arena called blanket actions. The likelihood of performing a blanket action is defined the same way as for the policy makers. The impact is obtained as shown earlier on. The impact is however spread on all actors concerned.

Finally, the external parties can influence the goals of the different constituencies through blanket influence. This is similar to the blanket framing that is used on the actors within the policy arena but this time they affect the others' goals. The likelihood of an action being performed will depend on the difference in beliefs between the constituencies and the external party concerned and the affiliation of the external party performing this action. The impact will depend on the resources spent and the difference in beliefs.

Each constituency represent a sector of the electorate and is associated to a political affiliation. Each constituency represents a certain percentage of the total voter population. This representativeness of a constituency is what affects the amount of resources that is distributed to the different actors within the policy arena as mentioned previously. The constituencies can influence the policy makers present in the policy arena. The policy maker's goal beliefs tend to move towards the goals of their constituencies to increase their chance of remaining in office.

A second round can also be identified as a policy formulation round. In this round, the aim is to adopt a policy instrument based on the chosen agenda such that it is implemented in the world. Policy instruments are the specific mechanisms policy makers put in place in order to impact the issues discussed within the iterative stages. During the policy formulation round, the actors influence each other's beliefs similarly to the agenda setting round. The aim here is however different. Each actor selects a policy instrument based on

its expected impact in the world. This impact is assessed by the actors based on their beliefs of the change the instrument will have on the states of each issues compared to their own goals. Because the actors have a limited attention span, they can only select what they perceive as being the most appropriate policy instrument. They decide that based on the impact that the instrument have on their beliefs and based on which issues need to be addressed the most urgently. The interactions of the different actors are the same as for the agenda setting round. The likelihood of an action happening is however now determined based on the expected impact that each instrument has on the urgent issues in the actors' beliefs within the narrower field of issues selected in the agenda setting stage.

One main difference is that the policy formulation round does not end with the selection of an issue but the selection of a policy instrument. Furthermore, the policy instrument selected is only implemented if the number of policy makers that support that instrument is superior to the threshold required for the implementation of the instrument. This threshold can be a majority, a two third majority or unanimity.

The last round considered is a round that does not involve the actors. It is the world. In this round, the instrument that has been selected is implemented. The world is affected by that instrument and the states of the world change accordingly. This then has an impact on the belief of the actors present in the policy arena as the change in the states is conveyed by the external parties to the different actors.

Finally external events can be introduced in the model. Such external events can affect anything from the goal of specific agents for a specific issue to a new distribution of the constituencies. These external events are devised based on case studies. The modeller must then adopt the impact of an election into the model's framework to appropriately represent that election.

1.2. Three streams theory

The introduction of the three streams theory changes some of the aspects presented in the common core. These changes are performed to account for the concept of streams and of policy window. The iterative stages considered are the same as the iterative stages mentioned in the common core. The difference is present in what the actors present in the policy arena choose as an issue. The actors can now choose from a policy or a problem as called for in the three streams theory. The problems are obtained in the belief hierarchy of the actors while the policy are obtained in a **policy hierarchy**.

The policy hierarchy is a hierarchy containing policy instruments. These policy instruments have specific impacts on the issues present in the belief hierarchy of the actors. The concept of policy instrument is therefore the same as the one presented in the common core. Within the three streams theory, policy instruments are present in all iterative stages. Each of these impact is now subjective which means that they also represent beliefs on the effectiveness of the different policies. These beliefs can also be influenced by the different actors present in the policy arena.

Each actor first selects a policy or a problem. The problems are graded similarly to what was previously presented in the common core: based on the perceived urgency of the chosen issue. The policy are graded based on their impact on their associated issues. Whichever grade is the highest will be chosen by the actor. If the actor chooses a problem first, then s/he will have to choose an associated policy based on the effectiveness of the policies. Furthermore, all actions performed by that actor from now on will be on the beliefs

of other actors concerning the selected problem. These actions re the same as the ones in the common core. If an actor chooses a policy first, s/he will have to choose an associated problem based on urgency. Similarly to the problem, all actions performed by that actor from now on will be on the beliefs of other actors concerning the selected policy.

The policy actions are similar to the problem actions presented in the common core for the different actors but with one change to the framing action. The aim of the actor is now to affect the impact beliefs of other actors in their policy network. The actions on policies are therefore akin to the framing actions related to the problems. This can only be done by actors having first selected a policy as mentioned earlier. There are some important caveats to this approach. First, the constituencies do not possess any beliefs on the policy hierarchy. This means that external parties cannot influence the constituencies if they have selected a policy first, they will then move on to their problem (which they selected based on the policy first chosen) and influence the constituencies on that problem. Second, the constituencies cannot influence the instrument hierarchy of the policy makers, the influence remains focused only on the belief hierarchy.

Additionally to the introduction of streams, the policy entrepreneurship model which is tied to the three streams theory introduces the concept of **teams**. Teams are small, short-term groups of actors which try to influence other actors on a specific problem or policy. These teams are constituted by actors when they consider that a policy or a problem is very urgent and when they can find other actors that share their beliefs on that policy or problem and the urgency of it. Once a problem or policy has been sufficiently pushed (enough actors have been influenced), then the team will disband and the actor will return to acting separately. Teams use the same actions as the individual actors. They provide actors with a larger policy network. This is because the team network consists of the sum of the networks of all actors present in the team. The teams obtain their resources from their members based on their feeling of belonging within a team. The actions performed by the team have to be agreed by the entire team as team are non-centralised entities. This means that no actor is powerful enough to impose his/her will on the other actors. Teams can also perform influencing actions on their own members. This helps increase the cohesiveness of the team so that they can last longer within the policy arena. The actions performed by team members on team members are blanket framing, influence on goals an influence on states.

Although there are also a set of iterative stages in the three streams theory, the actions performed in both iterative stages are not different anymore. Because each actor must have chosen either a policy or a problem, the actions are exactly the same in both iterative stages for all actors present in the policy network. The difference remains in the fact that for the agenda setting iterative stages, an agenda is set at the end which defines what is discussed thereafter. The agenda is composed of a problem and a policy. Each is chosen as being the most selected by the policy makers. The problems and policies discussed thereafter must relate to the problem and policy on the agenda. They must therefore be on a lower level in their respective hierarchies. For the policy formulation, the policy instrument chosen by the policy maker is the one that meets the threshold requirement once again. This disregard the fact that a policy maker might have chosen a problem first.

1.3. The advocacy framework coalition

The introduction of the advocacy coalition framework adds some different changes to the common core. The main addition is the concept of **coalitions**. The coalitions are groups to which actors are assigned based on their normative beliefs. They are long term entities that perform actions on other actors or other coalitions to influence them into similar beliefs. Actors only change coalitions when their normative beliefs vary which happens only rarely. The actions performed by coalitions are similar to the ones performed by teams. However, coalitions are centralised entities. This means that the **coalition** leader is the only actor that decides which actions are implemented. The coalition leader is the actor within a coalition that has the largest policy network. Finally, the number of coalitions present within a policy arena is usually limited to only a few according to the literature.

The ACF also introduces the policy broker. Policy brokers are actors that look in their network to put in contact actors which are badly connected within the policy arena. Policy makers, policy entrepreneurs and external parties can all be elevated to the role of policy broker which grants them additional actions. Two actions are added. With the first action, the policy broker can connect two actors which are not connected (but to which s/he is connected). In the second action, the policy broker can raise the awareness level between two actors (if his/her own awareness level is high enough). To perform these actions, the policy brokers is provided with additional resources fitting with the strength of his/her policy network.

Finally, which action is chosen by the policy broker is decided based on the type of policy broker. Neutral policy brokers will select the actions that will lead to the largest impact. This means that connecting actors that are not yet connected will come first, followed by raising the awareness between actors that are already aware of each other. If the policy broker plays an advocacy role, then s/he will select actions with actors that share his beliefs.

1.4. Feedback theory

For the feedback theory, the policy instruments implemented by the actors are supplemented with feedback effects. The feedback effects have an additional specified effect on different parts of the world or of the policy arena. When choosing for a policy instruments, the actors are not aware of the feedback effects. There are three feedback effects considered.

Some feedback effects have an impact on the constitution of the constituencies. The percentage distribution of each constituency will be affected. Some feedback effects have an impact on the belief hierarchy of the actors opening new issues to consideration in the hierarchy or removing others. Finally, a third feedback effect relates to the link between constituencies and the resources of the actors within the model. This links is affected by this type of feedback effects.

1.5. Diffusion theory

The introduction of the diffusion theory requires the consideration of multiple policy subsystems. These subsystems can represent different nations or cities for example but they are all regarding the same issues. The diffusion theory specifies the impact that the actors in a subsystem might have on actors of another subsystem. The subsystems share specific relationships ranging from **friendly** to **competitive** while considering **coercive** and

dominant. These relationships help define the actions that can be considered between the actors of the different subsystems. Each subsystem also possesses a certain **status**. This status helps define the amount of resources that is provided to each of their actors.

The actors in the different subsystems are all part of a **super-policy network**. This network connects actors between the different subsystems. Through this network actors can influence each other depending on the relationships between the arenas. An actor will consider all possible actions. The actions that is most likely to be performed is implemented.

The subsystems themselves are part of a network. Each subsystem has a link with another. Each of these links are one directional and can be of one type from friendly to competitive. Links that are coercive or dominant also gain a **strength** attribute. This strength attribute defines the influence that a subsystem will have on another when actors from one arena influence actors in the other. The actions that actors can perform is defined by the link that links their respective subsystems.

In the case of friendly relationship, the actor will be able to perform all actions that are available within the common core. These are actions of framing, influence on states and goals for the beliefs of the other actor. The likelihood of performing these actions along with their impact is assessed the same way as presented previously. When considering the diffusion theory with the common core or the ACF, then the actions are only performed on the issues. When it is considered with the three streams theory, then problems and policies actions are possible.

In the case of a coercive or dominant relationship, the actors will force their own goal beliefs onto selected actors in the other subsystem. The likelihood of this forced influence to be selected will depend on the conflict level between the actors and the type of actors that is being influenced (policy makers are more likely to be influence). Considering actions with an equal impact, actions on a dominant relationship will be most likely to happen, followed by coercive actions and finally friendly actions. The actual impact will only include the amount of resources spent, the difference in beliefs between the two actors and the strength of the considered subsystems. Once again, for similar actions, the impact will be largest in a dominant relationship.

In the case of a competitive relationship, the actors within one subsystem will seek to get a better world that the ones in other subsystems. To achieve this, they will change their goals to match the ones of other subsystems. This is also done through interactions. The likelihood of performing such an action along with their impact will is calculated similarly to the actions between friendly subsystems. The main difference with respect to the impact is that the impact of the actions are on the actor performing the action (the actor influences him/herself based on the beliefs of an actor in another subsystem).

2

The Formalisation

Due to the iterative process and after a reflection period, several parts of the formalisation was modified. This was done after the code had been implemented, it is therefore not mentioned in the main body of this report. The changes considered are presented here with a full rewrite of the formalisation.

2.1. Common core

The common core is the centre part of the model which contains the concepts that can be placed in common for all policy making theories. The different parts of the common core are addressed here in the same order as they were addressed in the conceptualisation in **??**.

2.1.1. The subsystems

The policy arena is designed as a subsystem in this formalisation. This term is borrowed from the advocacy coalition framework and represents the arena in which all the actors interact and influence on another. Each subsystem contains the different rounds: agenda setting, policy formulation and world.

2.1.2. The agents

The model is composed of five types of permanent agents and one temporary agent. These are divided in two main categories: the agents considered as they have to spend resources to perform actions and the agents that are passive as all the actions they perform happen regardless of resources or of the situation. One agent fits in both categories.

Active agents The active agents are the policy makers, the policy entrepreneurs and the external parties. Note that the external parties also have a passive role in which they provide the states from the truth agent, to the policy makers, the policy entrepreneurs and the electorate. This is considered to be a passive action as it is independent of resources.

The active agent's attributes are given as follows:

1. The *active agent* is represented as an 10-tuple given by `agent = (ID, subsystem, type, beliefHierarchy, affiliation, advocacy, resources, coalition, team, networkStrategy)` where `ID` is the unique ID of the agent, `subsystem` is the subsystem ID in which the agent is present, `type` is the choice of agent type, `beliefHierarchy`

is the agent's personalised belief hierarchy, `affiliation` is the political entity the agent identifies with, `advocacy` is the list of the issues the agent is supporting, `resources` is the agent's resources (a relative value), `coalition` is the coalition ID to which the agent is a member of, and `team` is the team ID to which the agent is a member of, `networkStrategy` is the strategy that the agent will use for his/her networking actions.

2. A *type* corresponds to a choice of agent. This can either be a policy maker, a policy entrepreneur or an external party. Depending on the type of agent, the actions will change from one agent to another.
3. The *belief hierarchy* is made of two main parts: the agent's own belief hierarchy structure and associated values, and the belief hierarchies of all other agents and their values based on the agent's perceived knowledge of their beliefs (also referred as partial knowledge). The entire *belief hierarchy* structure is therefore a list of belief hierarchies which is as long as the number of agents present in the model. The details of the hierarchy structure itself are provided later on.
4. The *advocacy* is represented as a 4-tuple `(prob_as, pol_as, prob_pf, prob_as)` where `prob_pf` is the problem chosen by the agent during the agenda setting process, `pol_as` is the policy chosen by the agent during the agenda setting process, similarly `prob_pf` and `pol_pf` are the problem and policy selected by the agent during the policy formulation process. Note that some of these might not be used depending on the theories considered at any point. For the common core, only the problem is used.
5. The *resources* are represented as a decimal on the interval [0, 1]. Resources are distributed to the agents based on their affiliation and on that affiliation's representation within the model. These resources are used by the agent to perform actions on other agents. The resources are relative amongst all agents.
6. The *team* is represented as a 3-tuple given by `(team ID, belonging, strategy)` where `team ID` is the team to which the agent belongs, `belonging` is the agent's feeling of belonging in a team and `strategy` is the agent's strategy when wanting to create a new team. This attribute is only used in the three streams theory. The *belonging* value relates to how much the agent feel (s)he is part of a team and defines the amount of resources the agent is willing to commit to his team. The *strategies* refers to the strategy selected by the modeller for an agent when it comes to the creation of a team.
7. The *coalition* is represented as a 2-tuple given by `(coalition ID, belonging)` where `coalition ID` is the coalition to which the agent belongs and `belonging` is the agent's feeling of belonging in the coalition.

Passive agents The passive agents are the truth agent and the electorate. Both types of agents only perform passive actions.

The truth agent: The truth agent is an agent not mentioned in the conceptualisation but required for the formalisation. This agent helps make the link between the world and the agents within the model. It gathers all the states of the world and provides them, as they are, to the external parties. One truth agent is present per subsystem. The only attribute of the truth agent is the belief hierarchy. This is a different one that for the active agents. It only contains the overall similar structure without any causal relations. Furthermore, it only contains the states for each of the issues.

The electorate: The electorate represents the different constituencies within a subsystem. There are as many electorate agents as there are political affiliations in the model per subsystem. The role of the electorate is to influence the policy makers in their aims. The following defines the attributes of the electorate.

The *electorate* can be given as a 6-tuple written as: `electorate = (ID, subsystem, affiliation, beliefHierarchy, representation)` where `ID` is the unique name of the electorate, `subsystem` considers in which subsystem it is, `affiliation` is its associated affiliation, `beliefHierarchy` is the associated belief hierarchy of the electorate and `representation` is the percentage of the total population which this electorate represents within the model. The sum of all *representation* from all electorates must always be equal to 100. The `representation` parameter affects the amount of resources received by the agents in the model. The belief hierarchy of the electorate is similar in structure to the one of the truth agent. It only contains the issues.

2.1.3. Belief hierarchy

The belief hierarchy is composed of two main parts: the issues and the causal relations. The issues are categorised in multiple layers: the deep core issues (the top layer), the policy core issues (the middle layers) and the secondary issues (the bottom layer). Secondary issues are linked to policy core issues through causal relations while policy core issues are linked to deep core beliefs through different causal relations. If multiple layers of policy core issues are present, each layer is also linked to each other with causal relations. The overall representation of this hierarchy structure is shown in Figure 2.1 for a three layered hierarchy.

Each issue is categorised by four parameters: the state, the aim, the preference and the awareness. The state defines the view of the agent of a certain issue as it is in the world. This view does not have to match reality and can be influenced by other agents. The aim shows what the agent would like to see happening in the world. The preference which is a derived parameter, defines the urgency that the agent places on the each issues. It is calculated depending on the state of the issue, the aim of the agent and the causal relations linked to this issue. The sum of all preference weights on any single layer of the belief hierarchy have to be equal to 1. Finally, the awareness represents the fact that agents are aware of a specific issue or not. It can take the value of 0 or 1. If an agent is not aware of an issue, it will not consider it in any calculation as if it did not exist. The belief hierarchy structure also contains causal relations. These link the issues on the different layers of the structure. These are the representation, in the agent's mind, of how each of the issues are related to each other within the technical model and which issues affect which other issue.

Each agent has an attribute called `beliefHierarchy`. This attributes contains two parts as mentioned previously: the agent's own belief hierarchy and the perceived hierarchies of all other agents in the model. It can be written as follows:

$$beliefHierarchy = [own_{hierarchy}, others_{hierarchy,n}] \tag{2.1}$$

where n represents the number of agents present in the model.

To further specify the hierarchy of the agent considered, the following can be said:

$$\begin{aligned} own_{hierarchy} &= [issues_k, causal\ relations_l] \\ issues &= [state, aim, preference, awareness] \end{aligned} \tag{2.2}$$

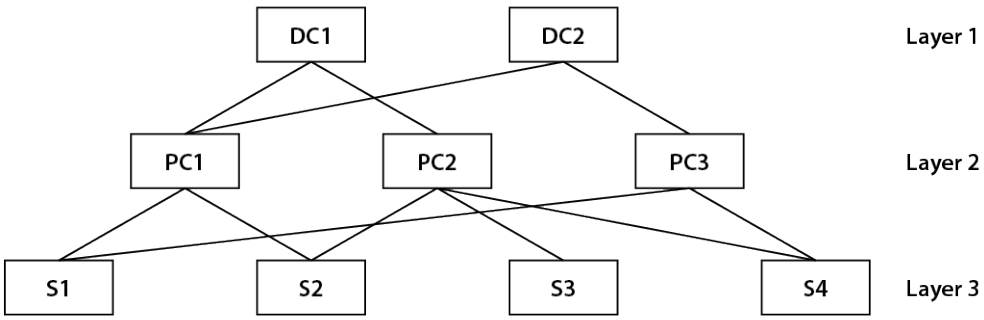

Figure 2.1: Example representation of a belief system with the three layers and several links between the layers. Not all possible causal relations are represented.

where k defines the number of issues present in the belief hierarchy structure and l the number of causal relations.

And it is also possible to specify the structure used to saved the perceived knowledge of the belief of the other agents:

$$\begin{aligned} other_{hierarchy} &= [issues_k, causal\ relations_l] \\ issues &= [state, aim] \end{aligned} \tag{2.3}$$

In both cases, the issues are specified with deep core issues first, policy cores following and ending with secondary issues. The causal relations are specified in the following example order: DC1-PC1, DC1-PC2, DC2-PC1, DC2-PC2, PC1-S1, PC1-S2, ... The state, preference and causal relation parameters are then specified on the interval of [-1, 1]. The preference is a percentage based parameters and is therefore calculated to be a number on the interval [0, 1].

2.1.4. Policy network

The policy network is the network that links all agents within a subsystem. This network is composed of links with the following attributes:

1. A *policy network link* is represented as a 7-tuple `link = (agent1, agent2, awareness, awarenessDecay, conflictLevel)` where `agent1` and `agent2` are the agents at the end of a link, `awareness` is the awareness value, `awarenessDecay` is the decay value at which the awareness diminishes per time interval and `conflictLevel` is the conflict level characterising the relation between two agents for specific issues.
2. The *awareness* value can take three main values. The value -1 refers to the fact that both agents are not aware of each other's existence. They cannot network together without external introduction from a third party. For the value 0, the actors have no connection but know each other exist. They cannot network together until they have raised their awareness level to a non-negative value through networking actions. Any positive integer relates the value of awareness between the two agents. The awareness is given on the interval $]0, 1]$. Note that awareness is relative amongst all links. The policy network links between policy makers can never be -1 as policy makers are public figures. Furthermore, a link cannot be downgraded to -1, it can only start at -1. As the awareness decays over time at a specific rate, there are several actions

or events that can lead to a growth or stop the decay in the awareness between two agents. This is detailed later on.

3. The *awareness decay* is represented by a 3-tuple `(value, time)` where `value` is the current value of the decay coefficient and `time` is a countdown. This countdown is by default set at 0, at which point decay of the awareness will happen. The countdown can be set at different values depending on actions that agents performed. The countdown will then go down to 0 every tick by 1. Whenever the countdown is not at 0, the decay is stopped.
4. The *conflict level* parameter is determined for each agent for each issue's aim and state and for causal relations. Note that the conflict level between two agents will be difference depending on which agents is considered as the conflict level is obtained based on the perception of another agent's beliefs. The conflict level is therefore given as a 2-tuple for each link: `(agent 1, agent 2)`. Then for each agent, the conflict level is defined per issue for the state and then for the aim, and all causal relations. The conflict level is then calculated using:

$$\begin{aligned} CW\ conflict\ level_{n,n_m} &= |CW_n - CW_{n_m}| \\ aim\ conflict\ level_{n,n_m} &= |A_n - A_{n_m}| \\ state\ conflict\ level_{n,n_m} &= |S_n - S_{n_m}| \end{aligned} \tag{2.4}$$

where CW the causal weight, A is the aim, S is the state, n is the agent for which the conflict level is calculated and n_m is the perceived belief of agent n on agent m for that specific issue.
The resulting value is then formatted into a coefficient to be used in the grading of actions as is shown later on. When the result obtained is between 0 and 0.25, the conflict level is considered to be low, the coefficient is then set at 0.75. When the result obtained is between 0.25 and 1.75, the conflict level is considered to be medium, the coefficient is set to 0.85. Finally for a result higher than 1.75, the conflict level is considered high and the coefficient is set to 0.95. Note that both the intervals and the resulting coefficients can be varied by the modellers during experimentations to better tailor their model to their case studies.

Network upkeep and maintenance Each agent must maintain his/her policy network. For this, 20% of agent's resources can be used. The agents are allowed five actions, each time spending 4% of the total amount of resources for each action. The order in which agents are selected to perform their network actions is random. These numbers can be changed by the modellers for the purpose of theirs cases.

Two strategies are differentiated for these actions. The modellers have to specified which strategy each agent uses in the model inputs. They are given as follows:

1. Largest network strategy - the agent will look into increasing his/her network as much possible:
   (a) The agent first wants to keep all links active. Any link that is below 30% awareness level will be targeted for action. The lowest, but still above 0, will have priority.
   (b) If all links are above 30% awareness, the agent will look into introducing new links which had 0% awareness. The priority is placed on the link with agents

with the closest beliefs.

(c) If there are still resources left after step 1 and 2 are complete, the agent will maintain the links with the lowest awareness level in the network.

2. Focused network strategy - the agent will focus on maintaining a network of agents sharing its beliefs: (note that when it is stated similar belief, this relates to the problem that the agent is advocating for and no other issue)
   (a) The agent will look first for link where an agent with a similar belief (one of the agents has his belief within 0.2 of the other agent's aim belief) or higher belief level and with a awareness which is lower than 70%. The agent will prioritise based only on the awareness level as long as the belief criteria is met.
   (b) If no link qualifies, then the agent will seek to introduce new links in his/her network. The agent will select agents that have a similar belief or higher belief level.
   (c) If both step 1 and 2 are met, the agent will look into maintaining an awareness level above 70% for links still in service. The priority is put on the links with the lowest awareness value.
   (d) If all previous steps are met, then the agent will simply look for new links with the priority placed on agents sharing his/her beliefs.

The different actions mentioned above are performed as follows:

- An agent can increase the awareness in a network link if he feels the awareness level is too low. This awareness maintenance is dependent on three main parameters: the resources spent and the affiliation of both agents. The total increase in awareness for such an actions is calculated as:

$$awareness := awareness + resources \cdot affiCoef_{Aff_n, Aff_m} \tag{2.5}$$

  where the $affiCoef_{Aff_n, Aff_m}$ is the weight related to the affiliation of the two agents. If they share the same affiliation, then it is equal to 1.
- Agents can also establish links with other agents for which they know they exist. This action can only be performed when the `link.awareness` parameter is equal to 0. If this is the case, then the awareness can be increased through the spending of resources. The new awareness level is then calculated similarly to the awareness maintenance but with a small malus to account for the initial investment costs. The equation is given as follows:

$$awareness := resources \cdot affiCoef_{Aff_n, Aff_m} \cdot 0.5 \tag{2.6}$$

- The notion of similar belief is defined as agents being close for the aim on issues at the policy core level. There are several steps to seek agents with similar beliefs:
  1. Seek all links with awareness equal to 0 or higher and select their associated agents.
  2. Select the aim parameter of the problem of the original agent.
  3. For each associated agent, check its aim parameter for this same problem issue.
  4. Calculate the difference of the parameter between the original agent and the associated agent for this issue.
  5. Rank all differences from lowest to highest where the lowest is considered to be an agent of similar beliefs.

This ranking is calculated based on the agent's partial knowledge of other agent's beliefs.

2.1.5. Affiliation network

The affiliation network is a network that looks at the political affiliation of the different actors. Its links are represented as a 3-tuple given by `(affiliation1, affiliation2, affiCoef)` where `affiliation1` and `affiliation2` are the affiliations that are connected by the link and `affiCoef` represents the influence that an actor with an affiliation 1 can have on an actor with affiliation 2. The *affiliation coefficient* is given on the interval $[0,1]$.

2.1.6. The actions - Policy Makers

There is a set of actions that policy maker agents can perform within the model. These actions are individual framing where the causal relations are the target of the influencing action, aim influence where the issue aim is the target of the influencing acton and state influence where the issue state is the target of the influencing action. These three times of actions are presented below in more details.

When selecting an action, the agent will perform all possible actions and calculate the likelihood grade of all actions. The agent will then select the action with the highest grade as the action to be implemented. The calculation of the likelihood of perfuming an action is mostly based on the beliefs of the influencing agent and his perception of the beliefs of the influenced agent. However, the actual impact of the action is based on the beliefs of the influencing agent and the beliefs of the influenced agent. This is an important difference that can sometimes justify why meaningless actions are performed. This can be due to a false perception of another agent's beliefs.

Individual framing The agents can attempt to influence the causal relation belief of other agents. This is an individual framing action. For this action, all causal relations related to the issue selected by the agent are considered. The likelihood to perform such an action depends on several parameters which are outlined below:

$$G_{CW,n_m} = conflictLevel_{CW,n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \tag{2.7}$$

where G stands for the grade, n is the influencing agent, m is the influenced agent. n_m is the perfection of the beliefs of the influenced agent by the influencing agent and CW is the causal weight of the causal relation

If this action is selected, as it has the highest grade, then the impact of the action on the beliefs of the influenced agents is given by:

$$CW_m := CW_m + (CW_n - CW_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \tag{2.8}$$

Individual action - Aim change The agents can also attempt to influence the aim beliefs on the different issues of the hierarchy of other agents. The likelihood that such action be performed is obtained in a similar way as shown below:

$$G_{A,n_m} = conflictLevel_{A,n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \tag{2.9}$$

The impact of such action is then calculated with:

$$A_m := A_m + (A_n - A_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \tag{2.10}$$

Individual action - State change Similarly to the influence on the aims of an agent, the states can also be influenced. The likelihood of such an action being performed is given as follows:

$$G_{S,n_m} = conflictLevel_{S,n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \tag{2.11}$$

And the impact is calculated as follows:

$$S_m := S_m + (S_n - S_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \tag{2.12}$$

2.1.7. Preference calculation (issues)

As mentioned earlier on, the policy maker has a limited attention span. This results in having to select one issue at a time for which (s)he thinks is the most urgent issue. This urgency is defined as the preference of an agent and is calculated for each layer in the belief hierarchy of the policy maker. Two cases must be distinguished for calculating this urgency: whether the layer considered is at the top or in the rest of the hierarchy. The preference is calculated for each issue and the sum of all preferences on each layer must be equal to 1.

Preference calculation for the principle beliefs For the top layer which is composed of the principle beliefs, the preference is calculated differently than for the other layers. This is because these beliefs are on the highest layer and can therefore not be connected to higher layers with causal relations. The calculation of the preference for each issue is given by:

$$P_i = \frac{|A_i - S_i|}{\sum_{j=1}^{n} |A_j - S_j|} \tag{2.13}$$

where j is defined at the number of principle belief issues and i characterises the principle belief issue being selected for the calculation.

Preference calculation for the policy core and secondary beliefs The preference calculation for the other layers in the belief hierarchy is adapted to include the causal relations that link these layers to higher up layers. This calculation applies to the policy core beliefs which are in the middle of the hierarchy and the secondary beliefs at the bottom.

To calculate the preference, the gap between aim and state for the issues is considered along with the impact of the causal relation on the gap of the issue on the above layers. The causal relations are not always helping bridge the gap between the aim and the state of issues on a higher layer. If this is the case, then the causal relations are not considered within the calculation as there effort is counter productive within the mind of the agent.

The resulting equation that can be used to calculate the preference for these layers is given by:

$$P_k = \frac{|A_k - S_k| + \sum_{j=1}^{n} |CW_j \left(A_j - S_j\right)|}{\sum_{l=1}^{p} \left[|A_l - S_l| + \sum_{j=1}^{n} \left|CW_{j,l} \left(A_{j,l} - S_{j,l}\right)\right|\right]} \tag{2.14}$$

The sums only include these terms if CW_j and $\left(A_j - S_j\right)$ have the same sign. If it is not the case, these terms are not considered. And where p is defined at the number of policy core issues, k characterises the policy core issue being selected for the calculation, j specifies the associated deep core and CW represents the weight of the causal relation.

Based on these preferences obtained, the agent will select one issue to advocate for as mentioned earlier. For each layer, the agent will choose the issue with the highest preference. This is the case for each layer. The actions that the agent will then perform will be to influence other agents on the issue they have selected specifically.

2.1.8. Partial knowledge and awareness decay

The likelihood of performing an action is based almost entirely on the perception of an agent on another agent's beliefs. This is also referred as the partial knowledge of an agent. This partial knowledge is the representation that agents have of other agent's beliefs. To perform better informed decisions, the agents must update their partial knowledge about other agents.

This update is performed after two agents have interacted with one another. When an action is performed, both agents have come into contact and have learnt about each other's beliefs on the issue they have interacted on. This allows them to gain knowledge about the other's belief. Therefore, for each action implemented, each agent will have access to the belief of the other agent concerning the issue influenced during the action. This access is not complete, the agents will gain the beliefs of the other agent with a small uncertainty amount.

Furthermore, because the two agents have interacted, their awareness of one another will not decline. It is therefore kept at the current level for several time steps. Only after these time steps have passed and if both agents have not interacted since, the decay of their awareness of one another will continue.

2.1.9. Agenda and agenda selection

The *agenda* is a 1-tuple given by `agenda = (issue, problem, policy)` where `issue` is the issue that is placed on the agenda by the policy makers, `problem` is the problem selected and `policy` is the policy selected by the policy makers. Note that the problem and policy attributes are only considered within the three streams theory, they are left empty within the common core.

To constitute the agenda, an issue has to be chosen for the entire subsystem. For this two methods are proposed which can yield different results. The first method considers all the top issues as graded by the policy makers. They are affected by their normalised resources. The grade of each issue is the sum of all agent's resources which have chosen that issue as their preferred issue. Whichever issue has the highest grade becomes the issue on the agenda.

The second method used for the ranking and selection of the issues is similar to the first one. The difference is that here all issues are taken from each policy maker. They are then weighed all together (and not simply the issues at the top of the ranking of each agent). This approach is meant to represent a different approach to the power dynamics in the model. The grade for each policy is then obtained as:

$$rankingGrade = \sum_{i=0}^{n} \left(\frac{1}{P_{rank}} \cdot resources_n \right) \tag{2.15}$$

where n is the number of agents and P_{rank} is the ranking of the policy for that agent. The issue with the highest grade is then taken as the issue for the agenda.

2.1.10. The actions - Policy entrepreneurs

The actions of the policy entrepreneurs are the same as the ones presented for the policy makers. The only difference is that the policy entrepreneurs cannot choose the agenda.

2.1.11. The actions - External parties

As mentioned in the conceptualisation, the have a more complex roles that the policy makers and entrepreneurs. They have different and similar actions to these actors. Their first role is to transmit the states of the world to the different agents in the model. This role is passive and does not require any resources. The second role is to blanket influence the electorates. For this 20% of the resources of the external parties are used spent in interval of 10%. The final role is an influencing role. Three actions are then available to the external parties: blanket framing, blanket aim influence and blanket state influence. 100% of the resources are allocated for this actions to be spent in intervals of 10%. For this all actions are graded and the one that is most likely to be considered is performed.

Transmitting the states The states of the issue in the hierarchy beliefs of all agents are updated based on the information they get from the external parties. These external parties have access to the full and real states of the world. They can obtain these states from the truth agent which has the complete set of the states for each issue directly from the world. Each external party selects states that (s)he finds interesting to transmit them to other active agents. This transmission of the states can be affected by the political affiliation of the agents as agents of different affiliation are unlikely to fully trust one another. The equation used to calculate this update of the states is given below:

$$S_{agent} := S_{agent} + \frac{1}{n} \sum_{i=1}^{n} \left(\left(S_{EP_n} - S_{agent} \right) \cdot affiCoef_{Aff_n, Aff_m} \right) \tag{2.16}$$

where S stands for the issue state, n is the number of external parties, EP stands for external parties and $affiCoef_{Aff_n, Aff_m}$ is the affiliation related weight. The affiliation coefficient is the one that relates the affiliation of the agent and the affiliation of the external party selected. If an external party has not selected that specific state, then (s)he will not be able to provide the state for that issue. Furthermore, the external parties will only transmit the states to agents within their network. This can lead to some agents lacking states for specific issues because of the composition of their policy network.

Electorate influence The external parties can also influence the goals of the electorate. This is done following the same template the goal influence of the policy makers and entrepreneurs. The only difference is that it is once again blanket influence which means that all electorate agents are affected at once. Note that because the external parties have a limited attention span, they can only influence the electorates on the issue they have selected. The impact of this influence is given by the following equation:

$$A_{El,i} := A_{El,i} + \left(A_{n,i} - A_{El,i}\right) \cdot affiCoef_n \cdot resources \cdot \frac{1}{nEl} \tag{2.17}$$

where n is the external party, i is the issue and nEl is the number of electorates.

Blanket framing The external parties can also attempt to influence the understanding of the world of other external parties, the policy makers and policy entrepreneurs. The external parties perform such influence on all agents at the same time which leads to this action being called blanket framing. The overall calculation of the likelihood of performing such an action is similar to what was presented for the framing action of the policy makers. The impact is also similar but spread amongst all agents. Such action can only happen on the agents that are within the policy network of the external party. All causal relations related to the issue selected by the external party can be influenced.

The likelihood of performing a blanket framing action is calculated as follows:

$$\begin{aligned} G_{CW,n_m} &= conflictLevel_{CW,n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \\ G_{CW,n} &= \sum_{m=1}^{nagents-1} G_{CW,n_m} \end{aligned} \tag{2.18}$$

where CW is the causal weight selected, n the external party performing the framing, m the affected agents considered and $nagents$ the total number of agents.

The impact of this action is then calculated for each agent using:

$$CW_m := CW_m + (CW_n - CW_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \cdot \frac{1}{nagents} \tag{2.19}$$

Blanket aim influence The external parties can also attempt to influence the aims of the other agents. This is done on all agents at once similar to the blanket framing.

The likelihood of performing a blanket aim influence action is calculated as follows:

$$\begin{aligned} G_{A,n_m} &= conflictLevel_{A,n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \\ G_{A,n} &= \sum_{m=1}^{nagents-1} G_{A,n_m} \end{aligned} \tag{2.20}$$

where A is the aim of the issue selected, n the external party performing the framing, m the affected agents considered and $nagents$ the total number of agents.

The impact of this action is then calculated for each agent using:

$$A_m := A_m + (A_n - A_m) \cdot resources \cdot affiCoef_{Aff_n, Aff_m} \cdot \frac{1}{nagents} \tag{2.21}$$

Blanket state influence Finally, the external parties can attempt to influence the states of the other agents. This is done on all agents at once similar to the blanket framing.

The likelihood of performing a blanket framing action is calculated as follows:

$$\begin{aligned} G_{S,n_m} &= conflictLevel_{S,n,m} \cdot affiCoef_{Aff_n, Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \\ G_{S,n} &= \sum_{m=1}^{nagents-1} G_{S,n_m} \end{aligned} \tag{2.22}$$

where S is the state of the issue selected, n the external party performing the framing, m the affected agents considered and $nagents$ the total number of agents.

The impact of this action is then calculated for each agent using:

$$S_m := S_m + (S_n - S_m) \cdot resources \cdot affiCoef_{Aff_n, Aff_m} \cdot \frac{1}{nagents} \tag{2.23}$$

2.1.12. Electorate passive action on policy makers

The policy makers are passively influenced by the electorate. Each electorate has a certain affiliation to which policy makers are also related. Each policy makers' issue aim will be influenced by their respective electorate. This happens as a passive effect where the issue aims of the policy makers slowly progress towards the issue aims of the electorate. The equation to calculate the change in the aim of the policy maker is given as follows:

$$A_{PM} := A_{PM} + (A_{El} - A_{PM}) \cdot 0.001 \cdot |A_{El} - S_{El}| \tag{2.24}$$

where El stands for electorate and PM for policy maker. Note that this is only performed for the issues of the policy maker for agents with matching affiliations. Furthermore, the value 0.001 is arbitrary and can be changed by the modeller depending on the case study.

2.1.13. Policy instruments

The policy instruments are measures that can are chosen by the policy makers to impact the real world. Policy entrepreneurs and external parties can also influence the policy makers in their choices. To assess the different policy instruments, the different active agents assess the impact of these instruments on the secondary issues in their belief hierarchy. These instruments have an impact on the gap between the states and the aim of each of these issues. The policy instruments can be described as follows:

1. A *policy instrument* is represented as a 7-tuple (`name, impact, change, layer, children, awareness, feedback`) where `impact` is related to the impact of the policy on a specific issue, `change` is the objective change expected in the world due to this policy, `layer` corresponds to the layer in the instrument hierarchy (when used),

`children` corresponds to the instruments linked to the selected instrument in the instrument hierarchy, `awareness` is related to the availability of the policy for a specific agent and `feedback` is related to the expected model feedback from the implementation of the policy considered.

2. The *impact* of a policy instrument is given as a 2-tuple: `(issue, impact)` where `issue` defines which of the secondary issues is affected and `impact` specifies by how much.
3. The *change* due to a policy instrument is the subjective representation of the impact of the policy instrument. These are the actual changes that will occur in the world with the implementation of the instrument. They are defined by the modeller and are fully independent on the agents.
4. The `layer` and the `children` are both parameters that related to the three streams theory. They are therefore outlined in that section and are left empty for the common core.
5. The *awareness* parameter defines whether a certain policy instrument is known in a specific subsystem. This parameter is related to the diffusion theory and is further outlined in the section dealing with the diffusion theory.
6. The *feedback* parameter contains the feedback effects as defined by the modeller. This parameter is related to the feedback theory and is further explained in the feedback theory section.

2.1.14. Preference calculation (instruments)

Similarly to the agenda setting round, in the policy formulation round, the agents have a limited attention span. They can therefore only select one policy instrument at a time. The calculations used to select these instruments are slightly different than the ones in the agenda setting. They are shown below

Preference calculation The preference calculation of the secondary issues within the context of a policy formulation rounds are tweaked from the calculation presented in the agenda setting round. The main reason is that for the policy formulation, the number of issues considered is narrowed down by what is on the agenda. The agents can therefore only consider issues in the secondary belief layer that have a direct effect, according to their beliefs, on the issue that is on the agenda. All other issues are not included within the preference calculation. For the rest, Equation 2.14 is still used to calculate the preferences of the different issues for each agent according to their own beliefs.

Instrument selection calculation Once the preferences for the different secondary issues have been attributed, it is possible to look at the preference of the instruments. These are used by the agents to assess the instruments and select the one they find most important. The equation that is used to calculate the preference of the different instruments is provided below. Similarly to the calculation of the preferences in the belief hierarchy, only instruments with impacts that have the same sign as the belief gap (aim minus state for a specific issue) are considered. The other instruments are counter productive and are therefore directly excluded from considerations.

$$P_i = \sum_{j=1}^{n} \left[impact_j \cdot \left(A_j - S_j \right) \cdot P_j \right] \tag{2.25}$$

where n is the number of impacts this policy instrument has, and j represents the secondary issue and the associated impact of the policy instrument on that issue.

Once all the preferences have been calculated, the agent will select the instrument with the highest preference. This will help define the actions that each agent can perform. Because no actions can be performed on the instruments directly, the agent will be able to perform actions on all issues directly related to the instrument and all causal relations which link the issue on the agenda and the issues related to this instrument. The likelihood and the impact of the actions are calculated in the same way as was shown previously. The aim here for the agents is to convince other agents that the instrument's impact is as high as they perceive because their causal relations, aims and states beliefs are similar.

2.1.15. Policy instrument selection and implementation

Similarly to the agenda setting round, the policy makers are the agents that can selected a policy instrument. Additionally, they will decide if a policy instrument should be implemented. This is done through one of two strategies which can be chosen by the modeller and which rare presented below.

Unanimity If unanimity is required, all policy makers must have selected the same policy instrument for it to be implemented. If this is not the case, the instrument will not be implemented and the round will close without a definitive output.

Majority If a majority is required, 50% plus one policy maker must select the policy instrument for it to be implemented. The resources of the different policy maker has no impact on this majority as it had in the agenda setting round. If a majority cannot be found, the policy instrument will not be implemented.

2.1.16. External events

The external events that are considered are external events that affect the agents. External events that would affect the world such as a flood for a hydrological model are of no interest and considered out of scope of this report. However, the impact on the model such as a change in the electorate composition due to the flooding is of interest.

The following is a non-exhaustive list of potential external events which the modeller could use.

1. An election - this would create a change in the electorate representation parameter which would in turn lead to different resources allocation for the policy makers.
2. The introduction of a new issue - a new issue could be introduced to the system or to a subsystem. This would affect the knowledge parameter for an issue for all agents present in the model.
3. Resources shift - a shift in the resources distribution due to an external event could be modelled. The way the resources are attributed could be modified to simulate a crisis situation were resources are scarce. This could also be modelled as a reduction in the

possibility of actions (increasing the amount of resources that is spent per action). parameter would be changed.
4. Policy network shifts - change in the awareness parameter of specific network links.
5. Affiliation network shift - change in the affiliation coefficient parameter that defines the interaction possibilities between two different political affiliations

2.1.17. The model cycle

For this formalisation, it is assumed that the different rounds are performed consecutively. First the agenda setting rounds are performed, then the policy formulation rounds and finally the real world. A further assumption is to assume that there is only one round of each of these steps is performed. This leads to a 3-step model with an agenda setting step, a policy formulation step and a world simulation step. The agenda which is obtained at the end of the agenda setting helps defines what the agents will be interacting about within the policy formulation.

This has several consequences. The first one is that the beliefs hierarchy of the agents must be a three-layer hierarchy. At the top are the principle beliefs, then in the middle the policy core beliefs and at the bottom the secondary beliefs. Within the agenda setting, the agenda decide on an agenda issue from the second layer, the policy core issues. Within the policy formulation, the agents select instruments which are related to the third layer.

The steps used to mode this approach are then detailed as follows:

1. World round:
   (a) *World simulation:* The world which is an exogenous party to the model or an internal technical model are run to provide inputs for the next step.
   (b) *Trigger of external events:* Any event that the modeller decides to implement are activated at this stage of the model cycle.
   (c) *Update of the truth agent:* The technical output is converted into normalised data fitting with the issues present in the belief tree. These are placed in the truth agent's S parameters.
   (d) *Electorate action on policy makers*
   (e) *Transmission of the states:* The external parties select their states of interest from the truth agent and pass the information to the agents within their policy network.
2. Agenda setting round:
   (a) *Preference calculation (issues):* Each agent calculates the preference for their principle and policy core beliefs. The agents then each select an issue that (s)he will advocate for in his/her policy core beliefs based on the preferences calculated.
   (b) *Agent interactions:*
      i. *Resources received:* Each active agent receives its resources based on his/her political affiliation.
      ii. *Network upkeep or maintenance*
      iii. *Belief influence actions:* All active agents perform their respective actions. The order in which the agents perform their actions is made random to not favour agents with first or last actions.
   (c) *Preference calculation (issues):* Each policy maker updates his preferences for his principle and policy core beliefs. This update of the preference is necessary

to take into account the changes that might have occurred as a results of the agent interactions. Each policy makers choose the issue with the highest preference as their issue of preference.

(d) *Agenda selection*

3. Policy formulation round:
   (a) *Preference calculation (instruments):* Each agent update his preference for his secondary beliefs based on the issue on the agenda. Each agent then selects a policy instrument that (s)he will be advocating for.
   (b) *Agent interactions:*
      i. *Resources received*
      ii. *Network upkeep or maintenance*
      iii. *Belief influence actions*
   (c) *Preference calculation (instruments):* Each policy maker upgrades their policy instrument preferences after the interaction step.
   (d) *Policy instrument implementation*
4. *The model advances:* The clock is advanced to the next tick. Programming of ticks actions are also performed (data collection, policy network awareness decay, ...).

2.2. Three streams theory

The three streams theory introduces a number of changes and additional concepts to the common core. These are detailed here. The first important addition and change is related to the policy instruments which are now assembled in an instrument hierarchy. Another change comes with the fact that the agent now must choose between a policy and a problem based on the calculated preference. Furthermore, because agents are not able to select policies, they are provided with an additional action. Finally, the agents can assemble in teams. This requires an algorithm for the creation of such teams and it brings in more actions that the actions can perform within and outside of their teams.

2.2.1. The policy instruments

As explained in the conceptualisation, the actors now each have an instrument hierarchy similar to their belief hierarchy. To formalise this hierarchy, two attribute within the policy instruments are activated. These are the layer and children attributes. The layer attribute defines in which layer of the hierarchy the instrument fits. These layers are related to the layers present in the belief hierarch. This means that policy instruments in the second layer of the instrument hierarchy will have an impact on the issues which are in the second layer of the belief hierarchy. The children attributes helps understand which instruments are related across the different layers. This is defined by the modeller and is useful to navigate from one round to another. When a certain instrument is placed on the agenda from the second layer, then only his children present in the third layer can be considered by the agents. All other instruments are considered irrelevant. A representation of the instrument hierarchy is given in Figure 2.2.

There is an additional change that occurs within the policy instruments. The impact is not objective anymore. The impact is now a subjective parameters very much like the states and aims for the issues in the belief hierarchy. This is important as the agents will be able to influence other agents on their beliefs of the impact of the different instrument

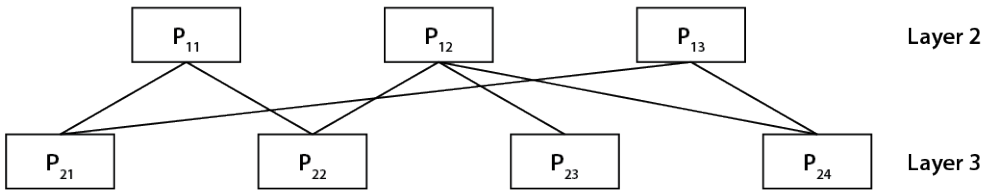

Figure 2.2: Instrument hierarchy representation with the two layers.

available to them.

2.2.2. Preference calculation (problems and policies)

As mentioned within the conceptualisation, the agents can now select a policy or a problem. For that they must grade all problems and policies in every layer. They can then select the policy or problem that has the highest grade.

Problem and policy preference calculation The problems and policy grades are obtained differently. The problems are based in the belief hierarchy and their grades are calculated similarly to the issues in the common core. The equation is given as:

$$G_{prob,i} = (A_i - S_i) + \sum_{j=1}^{n} \left| CW_j \left(A_j - S_j \right) \right| \tag{2.26}$$

where i corresponds to the policy core considered and j the related deep core issues.

The policy instrument are assessed on their impact on the different gaps in their associated issues in the belief hierarchy. The equation used to calculate their grades is given by:

$$G_{policy,i} = \sum_{i=1} (A_i - S_i \cdot I_i) \tag{2.27}$$

where i corresponds to the policy core affect by the policy selected and I is the impact expected from the policy.

Once all possible policies and problems have been graded, the agent will select the one with the highest grade. Then the process is repeated again but for the associated issues. This is done with only problems related to the policy selected if a policy was selected first or with the policies related to the problem selected if the problem was selected first.

The actions that the agents will perform will be based on whether they first selected a problem or a policy. These actions are detailed in a subsequent section.

Agenda and agenda selection Within the three streams approach, the agenda selection is a little different than for the common core. The agenda is now composed of two parts: a problem and a policy. The issue attribute of the agenda is left empty. The rest is similar to the common. The problem selected for the agenda is the most popular problem for all agents considering their respective resources while the policy chosen is the most popular policy amongst all agents also considering their resources.

Policy instrument selection and implementation For the policy formulation round, the procedure to select and implement a policy instrument is similar to the common core procedure. The policy chosen by all policy makers is considered. If a policy is beyond the threshold set but the modeller for implementation, the policy will be implemented. The problem chosen by the policy makers is not taken into account.

2.2.3. The actions (active agents)

The influencing actions that the agents can perform are mostly similar to the ones in the common core. The main difference is that all their actions are performed on the problems if they have first selected a problem. The policy makers and entrepreneurs can perform framing, state influence and aim influence actions on other agents based on the problem they have selected in their belief hierarchy. The external parties can perform their blanket framing on other agents and blanket aim influence on the electorate. This is also based on the problem they have each selected.

For the agents that have selected a policy, an additional action is added. This action is an action that influences the impact beliefs of the policy instrument selected by the agent. For all agent, this action replaces the framing or blanket framing action. The aim and state influence actions remain the same. The likelihood of performing each action is calculated. Whichever action is most likely to be performed is implemented with a certain calculated impact.

The likelihood of performing a policy action is given as follows:

$$G_{I_{issue},n_m} = conflictLevel_{I_{issue},n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \tag{2.28}$$

where n is the agent performing the action, m is the agent on which the action is performed, I stands for the impact that the action has on the mentioned issue. Note that if the instrument has an impact on four separate issues, then the agent will assess the likelihood of influencing each of the four impacts contained in that policy instrument.

The impact of the action is then given as follows:

$$I_{m,issue} := I_{m,issue} + \left(I_{n,issue} - I_{m,issue}\right) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \tag{2.29}$$

where n is the agent performing the action, m is the agent on which the action is performed.

2.2.4. The teams

As mentioned in the conceptualisation, the three streams theory includes the concept of teams. This concept is formalised within this section. Teams contain a number of agents that feel they share their beliefs for a specific issue. A team is therefore given as a 6-tuple written as: `(team ID, lead, members, issue, creation, resources)` where `lead` is the leader of the team (the agent that created the team), `members` is the list of members that are part of the team, `issue` is the policy issue that the team is advocating for (policy or problem), `creation` is the time at which the team has been created and `resources` consists of the resources at the disposal of the team to perform actions. The resources are calculated as the sum of all the members belonging level.

Agent-team actions The agent-team actions are all actions that each agent performs to either decide to join or create a team. It also consists of actions related to the disbanding of teams and the checking that the team requirements are still met. Each agent goes through all of these actions each tick. Each agent can only be part of one team at a time in the agenda setting process and one team in the policy formulation process. Note that all actives agents can be part of teams. The following list presents the different actions that are taken in chronological order in which they are performed in the model: start a team, join a team, leave a team, disband a team and calculate belonging level.

Start a team An agent that wants to start a team has to consider different requirements. Two different cases have to be considered here: the case where the agent first chose a problem and the case where the agent first chose a policy.

If the agent first chose a problem then the first requirement is that for the secondary issue chosen, the gap between aim and state must be above a certain threshold. This threshold is 0.8 in general but can be set to 0.5 in cases where a change in the magnitude of the state from the previous tick is larger than 0.5 (in case of an external event). This must be the case for all agents if they want to join the team. The second requirement relates to the belief states. For the agenda setting, it is the causal relation between the deep core issue with the highest preference for the starting agent and the policy core issue selected as the problem. For the policy formulation, the causal relation selected is the one relating the problem on the agenda and the secondary issue selected as the problem by the agent. All agents that want to join the team must be within 0.5 of the value of the causal relation for the agent starting the team.

If the agent first choses a policy, then there is a small change in the requirements looked at. The agent still looks at the gap requirement. However the second requirement is now dependent on the impact that the policy has on the secondary issues selected as the problem by the agent that is starting the team. The impact on the associated problem should be within 0.5 for the other agents considered to enter the team.

If both of these requirements are met, then the agents qualifies to join the team. Note that for each agent contacted, the agent starting the team loses 2% of his resources and the contacted agent loses 1% of his resources. This is to justify the resources needed for the exchange of knowledge. Furthermore, the agent starting the team will initially assess the other agents based on his knowledge of their beliefs. This leads to the spending of resources. If his perception of the other agent's beliefs are not true, then the agent will not join the team but the resources will have been spent regardless. The resources are also used to gain some information on the beliefs of the other agents. Even though the other agents might not be interested, spending these resources allow the agent to gain knowledge of the beliefs of the other agent within a certain range. Through this exchange of knowledge the agent also provides his own beliefs to the agent being contacted.

The creation of the team requirements are then based on the strategy that the agent is using. Two strategies are considered. The first strategy consists of starting a team with all the agents found that meet the requirements mentioned earlier. The team will then be composed of the maximum number of agents possible. The second strategy consists of starting a team once a certain number of agents has been established to meet the aforementioned requirement.

Upon the creation of a team, all agents that are part of the team are added to the mem-

ber list. The lead agent of the team is the agent that started the team. Each agent's belonging level is also calculated based on a weighted average of the beliefs of the team on the state of the issue advocated for. Joining a team will also lead to the half of the awareness decay in the links between the agents present in the team, effectively counting as an action.

Join a team An agent can join a team if (s)he is not already part of a team. For this, the agent will check the same requirements as when creating a team (gap and causal relation/impact requirements). This is done for the issue of the team (s)he is approaching. For each team that the agent probes, 2% of his resources are spent. If the requirements are met, then the agent will join the team and be added as a member of the team. The agent is allowed to spend 50% of his resources for such a search. Once these resources have been depleted or all team have been considered, the agent moves on.

Leave a team An agent can leave another team for one reason: because his belonging level is too low. The belonging parameter of the agent is checked every time period. If it descends below 30% then the agent will automatically leave the team. If the team remaining has less than three agents, it will be disbanded right away. Note that the belonging parameter is updated based on the perception of an agent on another agent's beliefs (partial belief) without full knowledge. This will artificially increase the life of teams.

Disband a team As mentioned earlier, a team will be disbanded if the problem or policy advocated by the team does not match the problem or policy advocated by the lead agent. This can be due to the leader being influenced and having changed his/her preferences. This is checked every five time periods. The second reason for which a team will be disbanded is if the agents present in the team to not meet the team creation requirements anymore. This is also checked every five time periods.

Belonging level setting The belonging level in a team is used to measure how much resources an agent is willing to contribute to the team resources and how much (s)he will keep for his own individual belief influence actions. This belonging level is entirely related to the problem or the policy being advocated by the team.

The belonging level is obtained differently depending on whether the team has selected an problem or a policy. For a problem, the belonging level is obtained through the problem that is being advocated by the entire team. The steps are shown below:

1. The weighted average of all agent's belief on the state of the problem being advocated by the team of all agent is calculated using:

$$S_{prob,weighted} = \sum_{i=1}^{n} resources_n \cdot S_n \tag{2.30}$$

   Note that this weighted average might be difference for each agent as it is based on partial knowledge and not full knowledge. The belonging parameter will be affected by the perception of other agent's beliefs.
2. The belonging level is then calculated using the following equation:

$$Belonging = 1 - \left| S_{prob,agent} - S_{prob,weighted} \right| \tag{2.31}$$

The belonging level in a team that is advocating for a policy is different. It is calculated using the impacts that the policy has on the different issues in the belief hierarchy. The belonging level of each agent is calculated as the difference between his/her own total belief and the average of the other agent's total beliefs. The 'total belief' of each agent is calculated for the policy that is being advocated by the team according to the agent's own beliefs as the sum sum of the absolute value of all impact that policy has. To estimate the total belief of other agents, agents have to rely on their partial knowledge. The steps are provided below:

1. The total belief of all agents is calculated:

$$TB_{pol,m} = \sum_{i=1}^{p} |I_{n_m,issue}| \tag{2.32}$$

   where m is the agent being considered, n the agent performing the estimation of the total belief and p the number of impacts that the policy instrument has.
2. The average of the other agent's total belief is calculated:

$$TB_{pol,avg} = \sum_{i=1}^{p} |TB_{pol,m}| \tag{2.33}$$

3. The belonging level is then calculated using the following equation:

$$Belonging = 1 - \left|TB_{pol,m} - TB_{pol,avg}\right| \tag{2.34}$$

Team belief actions Once the teams have been constituted, these teams must perform actions. These are the belief actions. There are two types of actions that the team can conduct. They can first perform intra-team actions to help the team get more consistent beliefs. They can also perform inter-team actions. In this case the aim is to convince other agents outside of the team that the belief of the team are more important. Each type of actions uses 50% of the resources reserved for the team. These actions are performed in intervals of 10% of the total amount of resources reserved. The resources available to team are equal to the sum of the belonging attributes for each of the members of the team.

- Intra-team actions:
  There are four main intra-team actions: blanket framing on causal relations, blanket framing on policy instrument impact, direct influence on aim and direct influence on state beliefs. The aim for these actions is to help the entire team be a more coherent entity with agents having similar beliefs regarding the issues they advocate for. As each of the team is based on awareness between the different agents, each agent has a say on which action should be chosen. Therefore each agent assesses all of the possible actions based on the partial knowledge he has of the other agents in the team. Because the agents are in a team, they all know fairly well the beliefs of the others in the team.
  Within the context of a team, these actions are performed by the team leader. Considering that the agents are all in the same team, they all know each other's almost exact beliefs and it therefore does not matter who decides on which action to take as the results will be the same.
  The blanket framing action on causal relation is used in the case where the team has selected a problem as the issue it is advocating for. The likelihood and impact of

such actions are the same as the ones presented in Equation 2.35 and Equation 2.23 respectively.
The blanket framing action on the policy impact is used in the case where the team has selected a policy as their issue. The likelihood of performing such action is calculated as follows:

$$\begin{aligned} G_{I,n_m} &= conflictLevel_{I,n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \\ G_{I,n} &= \sum_{m=1}^{nagents-1} G_{I,n_m} \end{aligned} \tag{2.35}$$

where I is the impact selected, n the agent considering the action, m the affected agents considered and $nagents$ the total number of agents in the team.
The blanket framing action on the problem is used in the case where the team has selected a problem as their issue. The likelihood of performing this action on the states is given by the following equation:

$$\begin{aligned} G_{S,n_m} &= conflictLevel_{I,n,m} \cdot affiCoef_{Aff_n,Aff_m} \cdot awareness_{n,m} \cdot actionWeight_{n,m} \\ G_{S,n} &= \sum_{m=1}^{nagents-1} G_{S,n_m} \end{aligned} \tag{2.36}$$

The likelihood for the influence of the aims of the problem is calculated the same way but through substitution of the conflict level from the states to the conflict level of the aims.
For each of these actions, the grade is the sum for all agents of the action. The total grades for each action is compared and the action with the highest impact is selected to be implemented.
The impact of all these actions is then given, in order, as:

$$\begin{aligned} CW_m &:= CW_m + (CW_n - CW_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \cdot \frac{1}{nagents} \\ I_m &:= I_m + (I_n - I_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \cdot \frac{1}{nagents} \\ S_m &:= S_m + (S_n - S_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \cdot \frac{1}{nagents} \\ A_m &:= A_m + (A_n - A_m) \cdot resources \cdot affiCoef_{Aff_n,Aff_m} \cdot \frac{1}{nagents} \end{aligned} \tag{2.37}$$

- Inter-team actions
  There are also four inter-team actions: framing on causal relations, framing on policy impact, direct influence on aim and direct influence on state beliefs. The aim for these action is to influence the belief of individual agents present outside of the team. These actions are graded by each of the agents present in the team and the action that has the most merit from all actions of all the agents is the one selected by the team

as a whole. To benefit better from the team, the agents can count on the overall team policy network and the team resources. The framing on causal relation is performed if the team has chosen a problem as its issue while the framing on policy impact is for when the team has chosen a policy as its issue.
To better benefit from the team network, a shadow network is established between the team and all agents outside of the team. The awareness for the established links is equal to the highest awareness found between one of the agents in the team and the outsider agent. The conflict level can then be calculated following two options: full knowledge assumption and partial knowledge assumption. The first option assumes that the team has full knowledge of the beliefs of outsider agents. The second option assumes that the team does not have full knowledge and therefore uses the partial knowledge of the agent with the higher awareness with the outsider agent. The conflict level are then calculated based on the difference between the outsider agent's belief (based on full or partial knowledge) and the average beliefs of the team for the issue selected. The links behave similarly to the normal links between the agents.
Each of the actions are performed using 10% of the resources of the team and using the partial knowledge of the agents within the team. As mentioned before, the awareness and conflict levels are obtained through the team-outside agent links.
The framing on causal relation likelihood grade is obtained using Equation 2.7, the state influence likelihood using Equation 2.11, the aim influence likelihood using Equation 2.9 and the impact influence likelihood using Equation 2.28
All of the actions are graded and the action with the highest likelihood to occur is the action that will be performed. The impact of each of these actions is then given by Equation 2.8, Equation 2.12, Equation 2.10 and Equation 2.29. Once an action is performed, the awareness decay in all links between all agents within the team and the agent being influenced is paused for a number of time steps.

2.2.5. Note on the agent individual belief actions

The agents which are part of a team can also perform actions as simple individuals similar to the actions performed in the backbone+ model. The resources used to this effect are the resources left depending on the belonging parameter. If the agent is team-less, then all his resources will go to performing individual actions.

The actions that the agent can perform are dependent on whether he has first chosen a policy or a problem similarly to the inter-team actions. In both cases, the agent can perform a state and aim influence action on other agents. Furthermore, if the agent has first chosen a problem, he will be able to perform a framing on causal relation action on causal relations related to the problem (s)he has chosen. If the agent has first chosen a policy, he will be able to perform a framing on impact action on all the impacts of the chosen policy. The likelihood and impact equations used are the same as the ones presented in the inter-team actions section. For the external parties, all these actions are blanket actions acting on all agents.

2.2.6. The model cycle

The model cycle used when the three stream theory is considered is given below. The parts that are common to the common core are not detailed but they are repeated for a better understanding.

1. World round:
   (a) *World simulation*
   (b) *Trigger of external events*
   (c) *Update of the truth agent*
   (d) *Electorate action on policy makers*
   (e) *Transmission of the states*
2. Agenda setting round:
   (a) *Preference calculation (problems and policies):* Each agent calculates the preference for their principle and policy core beliefs (policy and problem). The agents then each select a problem or a policy that (s)he will advocate for in his/her policy core beliefs based on the preferences calculated.
   (b) *Agent interactions:*
      i. *Resources received*
      ii. *Agent-team actions:* Each agent can decide to join or start a new team depending on his belief and his choice of policy or problem.
         A. *Belonging parameter update:* If an agent is in a team, then its belonging parameter is updated based on the latest beliefs.
         B. *Leave a team:* An agent will leave a team of his own accord only for one reason: if the belonging level drops below 30%. If the agent leaves the team he was part of, the team must then be checked to see if it has enough members. If it has less than three members it will have to be disbanded and all agents present in the team are removed from it.
         C. *Disband the team:* If the agent is the lead of the team, there is a possibility that he will disband the team. This happens when the policy issue the agent is advocating for changes and does not match the issue of the team anymore. This is checked every five ticks. If they do not match, the team will be disbanded and all agents removed from the team. The requirements used to create a team are also checked every five ticks to see if the members should still be in the team. If the number of members falls below three during this review process, then the team will be disbanded.
         D. *Join a team:* If the agent is not in a team, he will first try to join an existing team. For each team considered, he will spend a small amount of resources to gather information. If the gap in his beliefs is above the required thresholds for the issue that the considered team is supporting, and his state belief are closed enough to the team's leader state belief on that issue, then the agent can join the team.
         E. *Create a team:* If the agent has not managed to join a team, then he has the possibility to create a team himself. For this the agents looks towards the agents to which he is connected and has awareness. If the agent first chose a policy, then the agent will be able to start a team around that policy only. The same is true if the agent had chosen a problem. For each of these agents, the agent considers the gap in this issue along with the state to see if he shares beliefs with the other agents. Considering each agents costs a little resources for both the agent searching and the agents he is interacting with. Then depending on the per-

sonal strategy of the agent, the agent creates a team with all the agents he has found or he creates a team once he has found a sufficient amount of agents.

iii. *Team actions:* Each team performs their intra-team actions followed by their inter-team actions.

iv. *Network upkeep or maintenance*

v. *Belief influence actions:* All active agents perform their respective actions based on their remaining resources.

(c) *Preference calculation (problems and policies):* Each policy maker updates his preferences for his principle and policy core beliefs. This update of the preference is necessary to take into account the changes that might have occurred as a results of the agent interactions. Each policy maker then chooses first a problem or a policy with the highest preference as their issue of preference. They then select its associated policy or problem.

(d) *Agenda selection*

3. Policy formulation round:
   (a) *Preference calculation (problems and policies)*
   (b) *Agent interactions:*
      i. *Resources received*
      ii. *Agent-team actions*
      iii. *Team actions*
      iv. *Network upkeep or maintenance*
      v. *Belief influence actions*
   (c) *Preference calculation (problems and policies)*
   (d) *Policy instrument implementation*
4. *The model advances*

2.3. The advocacy framework coalition

The ACF introduces a number of new concepts. These concepts are an extension of the common core as was mentioned in the conceptualisation. They have no relation to the concepts presented in the three streams theory. The main new concept is the concept of coalition with is presented below.

2.3.1. Coalitions

The coalitions objects use a similar approach as the teams. A coalition is given as a 5-tuple written as: `(coalition ID, lead, members, issue, resources)` where `lead` is the leader of the coalition (the agent that created the coalition), `members` is the list of members that are part of the coalition, `issue` is the issue that the coalition is advocating for and `resources` consists of the resources at the disposal of the coalitions to perform actions. The resources are calculated as the sum of all the members belonging level.

The coalition are created based on the similarity of beliefs of the agents. Coalitions are created for each tick in the agenda setting process and the policy formulation process. In the agenda setting process, the coalitions are created based on their similarity of beliefs for a principle belief chosen by the modeller. For the policy formulation, they are created based on their similarity of beliefs regarding the issue that is on the agenda. These coalitions,

similarly to teams, can perform intra-coalition actions and inter-coalition actions using the resources that the coalition has at it disposal from its members. The actions that the agents part of the coalition can perform as similar to the actions presented in the backbone+.

2.3.2. Coalition creation

There are several algorithms that can be used to create coalitions. One is proposed here. First the leader of any potential coalition is selected. This is done by selecting the agent with the most amount of awareness throughout his/her policy network. This agent is assigned as the head of a coalition and must then constitute a coalition. In the agenda setting step, the coalitions are formed around a common principle belief. This principle belief is selected by the modeller at the beginning of the simulation. For the policy formulation, the agents will be gathered around the policy core beliefs that is on the agenda. The leading agent will look throughout his/her network of agents and will select all agents that are within a certain threshold value of his/her own state belief for the concerned issue. All these agents will be added to the coalition by default. This decision by the leading agent is based on the perceived knowledge (s)he has of the other agents. Note that during the creation of coalitions there is no exchange of knowledge between the agents. This is different than during team creation. This is because it is assumed that the leading agent looks through his network mentally and does not have to contact the different agents. This also means that the creation of a coalition is not a resource consuming process.

With the remaining agents present in the model which are coalition-less, the same steps are reproduced. The agent with the largest amount of awareness is selected and a coalition is created around him/her. These steps are repeated until less than 10% of the agents present in the model are left coalition-less.

The issue that will be advocated by the team is the one that the agent is supporting upon the creation of the coalition. Furthermore, the belonging level of the agents is calculated based on the issue being advocated by the team. This belonging value is calculated as the difference between the leader agent and their own belief values. This also means that the leader of the coalition will always have a belonging value of 1.

2.3.3. Intra-coalition actions

There are three main intra-coalition actions. These are the blanket framing of causal relations of the issue the coalition is advocating for, and aim and state influence actions on individual agents. These actions are performed in the same was as was presented in the three streams theory for the teams. These actions are the same in the agenda setting and the policy formulation processes. The difference relates to the issue that are being influenced only. Furthermore, the actions assessed are the ones that the leader of the coalition would make, and their assessment is based on the leader partial knowledge and his/her connection to the other agent. It is a centralised process.

2.3.4. Inter-coalition actions

The actions that can be performed by the coalition on agents are also limited to the three actions. These are framing on causal relation actions, and aim and state influence actions. These are once again similar to the actions presented in the three streams theory for the teams. The main difference in on how the actions are selected. Within the coalition framework, the actions are decided by the leader. Not all agents present in the team are

consulted. Only the leader looks at the possible actions and implements the actions. It is therefore important that the leader have a robust policy network.

2.3.5. The ACF cycle

The policy cycle that is used for the ACF is detailed below. The main difference with the backbone+ policy cycle is the addition of coalitions-related steps.

1. Tick initialisation:
   (a) *World simulation*
   (b) *Trigger of external events*
   (c) *Update of the truth agent*
   (d) *Electorate actions*
   (e) *External parties belief update*
   (f) *All agents belief update*
2. Agenda setting:
   (a) *Agent issue classification and selection*
   (b) *Deliberations:*
      i. *Resources received*
      ii. *Creation of the coalitions:* Agents are assigned to specific coalitions depending on the deep core belief of interest selected by the modeller.
      iii. *Coalition belief actions:* Each of the coalitions can perform their belief actions. These are once again split between the intra- and inter-coalition actions.
      iv. *Policy network upkeep or maintenance*
      v. *Individual belief actions*
   (c) *The policy makers rank the issues*
   (d) *Agenda setting*
3. Policy formulation:
   (a) *Policy pool selection*
   (b) *Policy instrument selection*
   (c) *Deliberations:*
      i. *Resources received*
      ii. *Creation of the coalitions*
      iii. *Coalition belief actions*
      iv. *Policy network upkeep or maintenance*
      v. *Individual belief actions*
   (d) *The policy makers rank the instruments*
   (e) *The system decides if a policy instrument should be implemented*
4. *The model advances to the next time step*

2.4. Feedback theory

The feedback theory focuses mostly on the policy instruments. It activates one attribute of these instruments: `feedback`. The feedback parameter defines what additional feedback can be expected from the measure. This feedback attribute is then formed of three parameters: `citizenship, groups and agenda`. This represent each of the feedback concepts taken into account in the model: impact on the electorate composition, impact on the re-

source allocation for policy entrepreneurs and impact on the knowledge of the belief tree respectively.

Not all feedback attributes need to be used for every instrument. This is up to the modeller to decide based on expected feedback of the instrument chosen. The different attributes are given below:

1. The *citizenship* attribute relates to the variation of the representation attribute of the electorate when applying the instrument. The electorate targeted along with the increase of decrease percentage of that electorate is specified within this attribute.
2. The *groups* attribute relates to the resources provided to the different groups of policy entrepreneurs and policy makers receive each round. Within this attribute, Within this attribute, the political affiliation considered is mentioned along with the percentage increase of decrease in the resources attributed to it. Note that this feedback does not apply at the agent level but at the political affiliation level.
3. The *agenda* attribute relates to the issues that the awareness attribute of the issues within the agents' belief trees. This attribute can change the awareness of specific agents to the issues in their belief tree. Depending on the feedback effect chosen, it will set the issue awareness to 1 for issues that are new to the agents and to -1 for issues that are removed from the agent's belief hierarchy. Note that this feedback effect applies to the entire subsystem at once and not to specific agents within a subsystem. Furthermore, it can affect more than one issue at a time depending on the modeller's inputs.

The feedback theory is considered to be an extension of the ACF and the three streams theory. It is therefore advised to use it with these theories and not only on the common core model. On its own, the effect might be limited or not apply at all.

2.5. Diffusion theory

The introduction of the diffusion theory brings in different concepts. The first important point is the fact that diffusion theory require a set of subsystems. Together they form the system. Each of these subsystems has its own policy network are presented above with a set of agents. Each agent has a certain belief hierarchy which is common to agents through the entire system (and so all subsystems). The policy instrument set used by the modeller is also a set used by the agents systemwide. Finally, each subsystem has a `status` attribute. This represent the influence of each of the subsystem and allows to assign resources that are used by the agents for the diffusion actions. Subsystems with a higher status will see its agents granted more resources compared to subsystems with a lower status. The two other main concepts are the super-policy network and the subsystem network. They are presented within this section.

2.5.1. Super-policy network

The super-policy network is a network that is modelled similarly to the policy network. However, it consists of links only connecting agents which are in different subsystems. The links attributes within this network are the same as the one in the policy network. The same maintenance actions are also performed within this network. Note that initially, this network is much sparser than policy networks. Furthermore, the awareness decay is also much lower than for other systems to maintain a large network without the need for con-

stant maintenance.

2.5.2. Subsystem network

The subsystem network is a network similar to the affiliation network between the political affiliations. It is however composed of directed links between the different systems. This network is exclusively used in the context of the diffusion theory as it requires numerous subsystems. Each link is has a certain type which defines the directed relationship between two subsystems. It can be friendly, dominant, competitive or coercive. More details are provided later on in this chapter. The different links, and the actions that can be performed by agents based on the relation between the subsystems are explained below. Similarly to previous models, the likelihood calculations for each of these actions are based on the agent's partial knowledge of other agent's beliefs. Furthermore, the agents influence agents in their network on the issues they think are relevant to them in their own subsystem. There is no systemwide agenda or policy instrument implementation.

Friendly link When an agent from system 1 interacts with an agent from system 2 and the link from system 1 to system 2 is friendly, the action performed will be very similar to the actions performed within the policy network. The actions possible will depend on the accompanying model. For the three streams models, the actions can be causal relation framing, impact influence, states influence or aim influence actions. For the ACF, the actors are limited to casual relation framing, state influence and aim influence. The aim within such a link is to have policy learning between the agents. The likelihood and impact of these actions are calculated similarly to what was previously shown.

Dominant/coercive link If the link is a dominant or coercive link, then the actor will impose his/her aim parameter on the other agent. This means that the agent will literally change the value of the aim of the actor (s)he is linked to. The change will be much stronger than for a simple friendly link action. It is still dependent on the same parameters as before but to a less extent. The actions available to the agents are the same as the actions in the friendly link case. However, some changes are added. The likelihood of performing an action does not depend on the political affiliation anymore or the awareness. It is only based on the conflict level. Furthermore, an added coefficient is placed on the impact. This coefficient is chosen by the modeller and is meant to make the impact of the actions much more potent than the action would be in a friendly link. The different equations are given below for the likelihood:

$$\begin{aligned} G_{CW,n_m} &= conflictLevel_{CW,n,m} \cdot actionWeight_{n,m} \\ G_{I_{issue},n_m} &= conflictLevel_{I_{issue},n,m} \cdot actionWeight_{n,m} \\ G_{S_{issue},n_m} &= conflictLevel_{S_{issue},n,m} \cdot actionWeight_{n,m} \\ G_{A_{issue},n_m} &= conflictLevel_{A_{issue},n,m} \cdot actionWeight_{n,m} \end{aligned} \tag{2.38}$$

And the impact for each of the actions is given by:

$$\begin{aligned} CW_m &:= CW_m + (CW_n - CW_m) \cdot resources \cdot coercionCoef \\ I_m &:= I_m + (I_n - I_m) \cdot resources \cdot coercionCoef \\ S_m &:= S_m + (S_n - S_m) \cdot resources \cdot coercionCoef \\ A_m &:= A_m + (A_n - A_m) \cdot resources \cdot coercionCoef \end{aligned} \tag{2.39}$$

Where $coercionCoef$ is the coercion coefficient which is dependent on the link considered. This coefficient is different between coercive links and dominant links.

Competitive link If the link is a competitive link, then the actor will seek to change his/her own beliefs according to what (s)he sees in another actor in a different system. The actor in system 1 will inspect the states of the actor in system 2. The action will consists of the first actor adjusting his/her aims to match the states of the second actor. The amount of adjustment will be dependent on the aforementioned parameters. This action is meant to display a need for the first actor to reach the same state as the one present in the second system. It is a competitive relationship. The likelihood and impact are obtained in the same way as for friendly links. However, the impact is not on the agent being acted upon anymore but it is applied to The agent acting. His/her beliefs are influenced by him/herself.

As done previously, each agent considers all possible actions for the different agents that are in his/her super-policy network. All likelihoods for all actions, regardless of the type of links between the subsystems in which the agents are, are calculated. The action that has the highest likelihood grade is then selected and the action is implemented.

The use of the diffusion theory is similar to the use of the feedback theory. Although it can be used without any other policy making theories, it is advised to consider either the three streams or the ACF theories with the backbone when using the diffusion theory.

2.5.3. The diffusion cycle

The cycle that is used for the diffusion must also consider all cycles of all subsystems. The assumption is that all internal decisions within the subsystems are performed prior to the diffusion-related actions. This means that actions that are performed at the system level will only have an impact on the subsystems within the next time period. The cycle is shown below:

1. Tick initialisation:
   (a) *World simulation*
   (b) *Trigger of external events*
   (c) *Update of the truth agent*
   (d) *Electorate actions*
   (e) *External parties belief update*
   (f) *All agents belief update*
2. Agenda setting:
   (a) *Subsystem related actions:* Each of the subsystems perform their agenda setting related actions.
   (b) *System deliberations:*
      i. *Resources received*

ii. *Super-policy network upkeep or maintenance*
iii. *Individual belief actions*

3. Policy formulation:
   (a) *Subsystem related actions:* Each of the subsystems perform their policy formulation related actions.
   (b) *Subsystem related actions:* Each of the subsystems perform their agenda setting related actions.
   (c) *System deliberations:*
      i. *Resources received*
      ii. *Super-policy network upkeep or maintenance*
      iii. *Individual belief actions*
4. *The model advances to the next time step*

Note that this cycle assume that there is only one world simulation for the entire system. In cases where the world simulation are also defined per subsystem, then the world simulation will be performed one by one in the tick initialisation phase and each subsystem will see its states updated accordingly.

3

Technical Model Formalisation

This chapter presents the approach that was used to code the forest fire world model. The model is based on the forest fire model presented in the Mesa project. It was modified slightly to add cells, add types of cells, add firefighters or prevention measures. This changes are limited as they only introduce probabilities of a fire happening or being suppressed. Furthermore, a timer was introduced to help the forest re-grow after a certain amount of time. This is used to be able to run the model infinitely.

3.1. Calculation of the states

The belief states are calculated for the truth agent. They are obtained using the following equations:

1. DC1 - Economy: A value of 1 would mean that the map is filled with empty and camp site cells and there was no fire. A value of -1 would mean that the whole map is filled with burnt cells.
$$Economy = \frac{Tourism + Safety}{2} \tag{3.1}$$
2. DC2 - Environment: A value of 1 would mean that the mao is covered in forest. A value of -1 would mean that the map is fully burnt.
$$Environment = \frac{Forest\ size + Safety}{2} \tag{3.2}$$
3. PC1 - Forest size: A value of 1 would mean the map is full of thick forest. A value of -1 would mean it is empty of all forests.
$$Forest\ size = \frac{0.75Thick + 0.25Thin}{Total} \tag{3.3}$$
4. PC2 - Tourism: A value of 1 would mean that the map is full of camps. A value of -1 would mean it is full of thick forest.
$$Tourism = \frac{0.75Camp + 0.25Thick}{Total} \tag{3.4}$$
5. PC3 - Safety: A value of 1 would mean that there is no burnt land. A value of -1 would mean that everything has burnt.
$$Safety = \frac{Monitoring + Firefighters + Prevention - Camp - Thick}{5} \tag{3.5}$$

6. S1 - Camp sites: A value of 1 would mean the map is covered with camps. A value of −1 would mean the map has no camps.

$$Camp = \frac{Camp}{Total} \tag{3.6}$$

7. S2 - Planting: A value of 1 would mean that there area lot of thin forests. A value of −1 would mean there is a no thin forests.

$$Planting = \frac{Thin}{Total} \tag{3.7}$$

8. S3 - Monitoring: A value of 1 would mean that the burning probability is of 10% for thin forest and 100% for thick forests. A value of −1 would mean the probability is of 0% for both.

$$Monitoring = 0.1 - burning\ probability \tag{3.8}$$

9. S4 - Firefighters: A value of −1 would mean that there is the maximum 50% of firefighters extinguishing the fire. A value of 1 would mean there is no change of extinguishing the fire.

$$Firefighters = 0.5 - firefighter\ probability \tag{3.9}$$

10. S5 - Prevention: A value of 1 would mean the map is filled with empty cells. A value of −1 would mean the map has no empty cells.

$$Prevention = \frac{Empty}{Total} \tag{3.10}$$

3.2. The policy instruments

A number of policy instruments are considered within the model. They are presented below. These instruments were obtained arbitrarily. The first ten instruments only affect one secondary issues in the belief hierarchy. For the last six, they affect a mix of secondary beliefs. Each instrument was chosen with its opposite. They are presented in Table 3.1

The policies used for the three streams theories at the policy core levels are also shown in Table 3.2.

Table 3.1: Policy instruments used affecting the secondary beliefs of the agents. Impact 1 is regarding camp sites, impact 2 planting new forets, impact 3 monitoring, impact 4 firefighters and impact 5 fire prevention.

Instrument	Impact 1	Impact 2	Impact 3	Impact 4	Impact 5
0	0.5	0	0	0	0
1	-0.5	0	0	0	0
2	0	0.5	0	0	0
3	0	-0.5	0	0	0
4	0	0	0.5	0	0
5	0	0	-0.5	0	0
6	0	0	0	0.5	0
7	0	0	0	-0.5	0
8	0	0	0	0	0.5
9	0	0	0	0	-0.5
10	0	0.2	0.3	0	0.5
11	0	-0.2	-0.3	0	-0.5
12	-0.4	0.5	0.1	-0.9	-0.5
13	0.4	-0.5	-0.1	0.9	0.5
14	-0.8	0	0	0.9	0
15	0.8	0	0	-0.9	0

Table 3.2: Policy instruments affecting the policy core beliefs (only used for the three streams model). Impact 1 is regarding forest sizes, impact 2 tourism and impact 3 safety.

Instrument	Impact 1	Impact 2	Impact 3
0	0.5	0	0
1	-0.5	0	0
2	0	0.5	0
3	0	-0.5	0
4	0	0	0.5
5	0	0	-0.5

4

The Model Parameters

This chapter presents the different parameters that are present within the model.

4.1. For the technical model

These are all the parameters that are related to the forest-fire model. These parameters are case study specific and will change when the case study is changed. The initial values used in the model for the experiments is shown in brackets.

1. The initial thin forest burning probability (0.2%): This defines the probability that a thin forest will combust for any tick.
2. The initial firefighter force (10%): This defines the probability that firefighters will intervene in a burning patch leading to a thin forest.
3. The multiplier coefficient between the thin forest burning probability and the thick forest burning probability (10): This relates to the probability that a thick forest will burn compared to the probability that a thin forest will burn.
4. Time for the growth from thin to thick forests (3): This relates to the number of ticks required for a forest to go from thin to thick.
5. Time between burnt patch and thin forest/empty patch (3): This is the number of ticks that it takes for a patch to go from burnt back to empty or thin forest.
6. The percentage between empty patch and thin forest when a patch is past burnt (50%): This is the probability that a burnt patch will go back to being empty versus being a thin forest.

4.2. For the technical-emergence bridge

The parameters mentioned here are the ones that are related to the calculation of the states and how the technical model is coupled to the emergence model. Changes in these parameters will affect the sensitivity of the emergence model to the initial conditions of the agent's belief trees. It also has an effect on the ultimate control that the agents will have on the overall technical model.

1. Maximum percentage of camp sites allowed (20%): This is used for the calculation of the states of S1.
2. Maximum percentage of thin forests allowed (60%): This is use for the calculation of the states of S2.

3. Maximum thin forest burning probability allowed (10%): This is used for the calculation of the states of S3.
4. Maximum firefighter force allowed (50%): This is used for the calculation of the states of S4
5. Maximum percentage of empty patches allowed (100%): This is used for the calculation of the states of S5.
6. Maximum percentage of thick forests allows (100%): This is used for the calculation of the states of PC3.

4.3. For the policy emergence model

This section presents all the parameters related to the policy emergence model. In square brackets there is a mention of when these parameters appear in the four different models (backbone, backbone+, three streams (3S) and ACF). In brackets are the values currently being used when they are needed. Explanations are provided when required.

1. Theory choice [all]: The modeller can choose which model to simulate which will select the appropriate cycle. The choice is between backbone, backbone+, 3S or ACF. All these models are mutually exclusive. However the backbone+ builds on the backbone, the three streams and ACF build on the backbone+.
2. The belief tree aims [backbone]: These are all the inputs required for the belief hierarchy of the agents per affiliation type.
3. Number of policy makers [backbone] (6).
4. Number of affiliations [backbone] (3): Note that this code is made to only work for three affiliations. More or less affiliation would require significant changes to the infrastructure of the code throughout all of the code.
5. The affiliation weights [backbone] (0.75, 0.85, 0.95): This defines the influence of agents from different affiliations in the following order: affiliation 1 - affiliation 2, affiliation 1 - affiliation 3, affiliation 2 - affiliation 3.
6. The policy instrument set [backbone]: This relates to the overall instrument set defines by the modeller providing policy instruments and their impact ton the different secondary issues.
7. The distribution of affiliation [backbone] (33,33,34): This defines the amount of resources each affiliation will have. It relates to the electorate representation. It needs to add up to 100%.
8. The electorate influence coefficient [backbone] (0.001).
9. Ratio of policy entrepreneurs per policy makers [backbone+] (3): This defines the number of policy entrepreneurs for every one policy maker agent added to the model.
10. Policy network strategy 1 maintenance and upkeep threshold [backbone+] (30%): This is the thresholds that defines what is the amount of awareness is needed for the links of every agent for the upkeep and maintenance actions.
11. Allowed resources for the policy network maintenance and upkeep actions [backbone+] (4%).
12. The different strategies for the maintenance of the agents networks [backbone+]: This parameter is agent dependent but is currently the same for all agents for simplicity and to have more consistent results.
13. The conflict level coefficients [backbone+] (0.75, 0.85, 0.95): This defines the coefficient used when the conflict is low, mild and high.

14. Partial knowledge sharing randomness coefficient [backbone+] (0.1): This is the coefficient use to set the randomness of the partial knowledge shared. For this value, a number between -0.1 and 0.1 is added to the actual value of the belief when the beliefs are shared after an action has been performed.
15. Action potency coefficient [backbone+] (1): This coefficient is used to make actions more potent. It is a tuning parameters that can be changed by the modeller to adjust the policy learning speed.
16. Resource spent per action coefficient [backbone+] (10%): This defines the amount of resources from the total resources used for actions that can be used for each action. In this case, it would allow every agent to perform 10 actions. This parameter can be used for tuning but also computational efficiency.
17. The awareness decay level coefficient [backbone+] (0.05): This defines by how much the awareness of any link will go down for every tick.
18. Minimum belonging level allowed [3S] (30%): Coefficient defining the threshold below which an agent will have to leave the team.
19. Inter-tick checks [3S] (5): This is the interval between which the agents teams are not checked on whether they still match the team creation criteria.
20. Agent team creation strategy [3S] (strategy 1): This is an agent related input. The strategies are defined in the formalisation. Currently, all agents have the same strategy for simplicity.
21. The number of agents required to start a team for strategy 1 [3S] (3).
22. The gap requirement for the creation of teams [3S] (0.8).
23. The state requirement for the creation of teams [3S] (0.5).
24. Resources used to contact agents for team creation [3S] (2%).
25. Resources used when being contacted for team creation [3S] (1%).
26. Resource spent per action coefficient for teams [3S] (10%): Similar to the backbone but for teams.
27. Principle issue selection for coalition [ACF] (P1): This is decided by the modeller and defines the coalition issue for the agenda setting process in the ACF.
28. The choice of threshold for the constitution of the coalitions [ACF] (0.35): This defines the interval within which a belief is considered similar for the creation of coalitions: [-0.35, 0,35] of the agent creating the coalition.

5
Verification

This chapter presents the verification in more details. The different methods that were used to checked the model are outlined. This is done by looking through the code and outlining the issues that arose for the different parts of the code.

5.1. The belief hierarchy

The belief hierarchy is one of the most complex part of the model. The belief hierarchy structure contains the beliefs of the agent plus the belief of all other agents (the partial knowledge). This is built into a multi-dimensional array.

The belief hierarchy is present throughout the model in most functions. The fact that it is such a complex array means that verification is required throughout to make sure that every time a part of this belief hierarchy is selected, the right indexes are chosen. If the right indexes are not chosen, the code will still run but the results will be completely wrong. This is particularly important for the causal relations which are saved in the array in a certain sequence mentioned within the code comments. Without following this sequence, the code would run but the results would be flawed as it would use the wrong causal relations.

5.1.1. Preference calculation

For the preference calculation, several checks were performed to make sure the right indexes are selected. The preference calculation is performed for the agent's own beliefs but also for all the partial belief hierarchies in the belief hierarchy parameter. This is needed for the calculation of the best actions later on in the model. For the principle belief calculation, the selection of the right issue was checked, and it was made sure that the preferences of the two issues added up to one. Note that this preference calculation works regardless of the hierarchy structure. Nothing has been hardcoded.

For the policy core belief preference calculations, the selection of the right issue was checked. The selection of only the causal relations with matching sign to the gap in the principle beliefs are also checked. Finally, it was checked that all the preferences on that level add up to one.

For the secondary belief preference calculation, a check was performed that only the issues related to the issue on the agenda are selected. Then the same checks were performed as the checks performed for the policy core beliefs.

For the preference calculation for the policy hierarchies, the same procedures were performed but with the different code considering each of the impacts for each of the instruments. For all these calculations, checks were performed throughout the coding of the rest of the code. Through these checks, it was uncovered that the wrong indexes were chosen in some parts of the preferences calculation. It can now be said with certainty that the right indices are being selected and that the preference calculations are correct.

5.1.2. Issue/instrument/policy/problem selection

The instrument selection was checked by comparing the actual instrument selected and the preferences of all instruments. The instrument with the highest preference must be the one that is selected by the agent. The same was done for the policies and problems for the three streams model. Check were also performed to make sure that the grade list matches the length of the number of issues being considered.

5.2. The individual actions selection and grading

Before any actions are performed, the resources are provided to the agents. This was checked through print functions to make sure that the resources were different for agents with varying affiliations as they should be and followed the representation of the affiliation. Furthermore, the resources are then split, for the policy makers and policy entrepreneurs. 20% goes to the policy network actions while 80% go to the individual agent actions. This was checked to make sure that the resources are divided properly.

5.2.1. Network upgrade and maintenance actions

The network actions are then performed by all active agents. For this, it was made sure that the list of agents is shuffled so that it is always a different agent that is selected first. Two algorithms are used here. One for the agenda setting and one for the policy formulation. For each two strategies are possible as developed in the formalisation.

Agenda setting For the first strategy, checks were performed on the while loops. These loops allow actions to be performed as long as enough resources are left. Checks were then performed to see whether the links added to the list of links to be maintained did indeed meet the requirements set by this strategy (lower than 30% awareness but above 0). It was also checked that the list of links and its associated list of awareness values were coherent with respect to indexes. Finally, checks were also performed to make sure that all links related to the agent performing the action are selected and not all links within the model.

Then for the actual maintenance of the links, it was checked that the right index of the link with the lowest awareness was selected in the list previously established. Then it was checked that the maintenance was duly performed. It was also checked that the affiliation be appropriately taken into account when increasing the awareness level. It was also made sure that if the list of links to maintain is empty, then the code moves to the next possible link maintenance. It was also checked that after each maintenance of a link, the appropriate resources are removed from the agent's resources associated to link maintenance.

For the creation of new links, it was made sure that this is only performed when all active links from the agent concerned are above 30%. Then a check was performed to see that only links with zero awareness within the agent's network be selected for the creation of a

new link (new links can only be created between agents that know that they exist hence not selecting awareness -1 links). Similarly to before, it was checked that when creating a link, the appropriate awareness be bestowed upon the new link and the resources be removed from the agent's available maintenance resources. *Looking at the code after implementation, it was found that the wrong equation was used for the creation of new links with the omission of the 0.5 coefficient. This had been added to the Further Work list in Chapter 6.*

Finally, for the third step, it was checked that this step be performed only if resources are left through the same while loop as before. It was checked that only links that are below 1 and not equal to -1 in awareness be considered. Similarly to before, checks were performed to make sure that the links be added the right amount of resources depending on the affiliations and the resources. it was also made sure that the resources be removed from the agent's resources after the action is performed. Finally, it was checked that if a link is maintained to a level higher than 1, its awareness be reduced back to 1 (no link is allowed to grow beyond 1 awareness).

For the second strategy, similar checks were performed. The main difference here is the order in which the steps are made and which steps are used. For example, it was checked that the agents must have similar beliefs. For this, it was checked and verified that the agents' aim of the problem be within 0.2 of one another for the three streams theory and the agents' aim of the issue be within 0.2 of one another for all other models. It was checked that the list of links considered is then appropriately formed. Then overall the checks are the same.

Policy formulation For the policy formulation, the checks are similar to the checks of the agenda setting process and the strategies are identical. The main difference arose in the second strategy and the definition of similar beliefs. Checks were performed to make sure that the similar beliefs relate to the issue or problem on the agenda in each cases. The rest of the code that was used was the same as the one for the agenda setting process.

5.2.2. External parties actions [Backbone/Backbone+/ACF]

The external parties can perform two actions and these actions are different in the agenda setting process and the policy formulation process. They are also different in the three streams theory as there a policy and a problem can be present. The resources for the external parties are split in two: 50% for the blanket framing and 50% for the electorate influence. The verifications performed are shown here.

Blanket framing (AS) The first checks performed for the blanket framing relate to the causal relations. Not all causal relations can be used for framing but only the ones related to the issue selected by the external party, It was therefore checked that the right causal relations are being selected. Then it was checked that the while loop used to make sure that the agent has enough resources does indeed work. Then for the grading of the actions, it was checked that the actions are graded appropriately based on the equations in the formalisation. It was also made sure that in case there is no partial knowledge, the partial knowledge be set to 0 so that calculations can be performed. It was checked that this be temporary and the None partial knowledge be re-applied after the action has been graded.

For the assessment of the list of grades, it was checked that the right action is selected by checking the grades through a print command. Then it was checked that the action is ap-

propriately applied to the right agent. For this several checks were performed by changing the number of agents manually and the number of causal relations. It was extensively cross checked with the number of grade recorded on in the lists of actions. Note that through this check, it was found several times that the actions performed were the wrong influence on the wrong agents. This has now been fixed. Finally, it was also checked that the resources be removed properly from the agent's available resources for blanket framing actions.

Electorate influence (AS) For the electorate influence, the actions are performed differently. This is because the new preference of the electorates is calculated used to obtain the grade. This required the copy of some of the data to have temporary changes in the beliefs of the electorates. This was extensively checked as it is known that copy functions can lead to issue with the reference to memory. It was therefore made sure that copying the data did not have an impact on the rest of the simulation later on. Associated with this action, the preference calculation of the electorate was also verified. This was done similarly to how the verification of the preference calculations of the other agent is performed. This is because the code is mostly the same, simply adjusted for the electorate. It was also checked that the grades assigned are the appropriate ones and that they are stored in the right order.

Finally, similarly to the blanket framing, the implementation of the actions was checked several times. This was once again done to make sure that the right action is applied on the right electorate. Furthermore, it was checked that the right amount of resources are removed from the agent's resources after each implementation of an action.

Blanket framing (PF) The main difference between the agenda setting and the policy formulation is the choice of causal relations. This was therefore implemented and checked to make sure that the actions are now performed on the causal relations related to the agenda chosen by the actors. Considering most of the code was re-used from the previous agenda setting section, the checks performed were then the same.

Electorate influence (PF) This is similar for the electorate influence. The only difference between agenda setting and policy formulation is related to the issues that are being influenced. The other checks were the same as the ones presented before.

5.2.3. External parties actions [3S]

For the three streams theory, most of the code was changed. This is because the agents are not using issues anymore but they are using a policy or a problem. Therefore, although the code infrastructure remains the same, most of the code had to be rewritten. Checks were used to make sure that the agents are performing the actions based on their initial choices between problem and policy. The same checks where then performed as previously. For the problem, the choice of causal relations were checked while for the policies, the choice of impact of the policies was checked. The equations to calculate the grade of each of the actions and the implementation of the actions were also checked. This is valid for both the agenda setting process and the policy formulation process.

5.2.4. Policy makers and entrepreneurs actions [Backbone/Backbone+/ACF]

The actions of the policy entrepreneurs and policy makers are exactly the same. They are constructed in a similar fashion to the actions of the external parties. The main differences

are the types of actions that are available to them. This is outlined here.

Agenda setting There are three type of actions that the actors can perform: framing, state influence and aim influence. All of these actions are assessed at the same time and the grades are compiled into a long list. This is done for each agent. Once the list has been complied, the action with the highest grade is selected and it is implemented. The list length is therefore the number of causal relations plus two times the amount of agents that are connected to the agent performing the actions and which have an awareness higher than 0. The first verification is performed on the creation of this grade list. It is made sure that only the appropriate are considered for actions. Then it is checked that all actions grades are obtained appropriately. The checks are mostly important for the temporary assignment of the value 0 when no partial knowledge is present in the agent's belief hierarchy. This has shown to cause memory assignment issues in the past.

Then comes the part where the best action is selected. It easy to select the action by simply finding the minimum grade. It is however trickier to define what action that is and on which agent. This was therefore verified after it was found that the wrong actions were selected.

Then there is implementation of the actions. Depending on the action selected the action is implemented on specific actors. The equations here are mostly the same as the ones used for the assessment of the grade. The main different is the use of actual belief and not the partial beliefs anymore. The actions were thoroughly checked to make sure the right outcome is produced. A check in the code is also added to make sure that no beliefs goes above one or below minus one.

Policy formulation For the policy formulation, the steps are broadly the same. The main difference here relates in which issues are chosen and which causal relations are chosen. Once that is verified, the rest of the code is broadly the same and the verification checks used are also the same.

5.2.5. Policy makers and entrepreneurs actions [3S]

Similarly to the addition for the external parties, the addition from the three streams model to the actions of the policy makers and policy entrepreneurs are significant. They required the writing of an entire new code but based using the infrastructure of the other models. The actions related to the problem are mostly the same as the one for the other models. The verification procedure is therefore the same. The main issue there was to identify the right indexes in the belief hierarchies of the actors as the notation is different between problem and issue.

For the policy, an entirely new code has to be put in place. It provides the same state and aim influence actions but a completely new impact framing action that had to be verified to make sure that the impact is calculated appropriately.

Beyond these changes, the rest of the code is very similar in architecture. The grades are placed in a list (different for the problem and the policy) and the lowest grade is the one selected to be implemented. Then it becomes a question of finding out what exactly that action was and to implement it on the right actor.

Checks were performed throughout the code (and the infrastructure is still there). This was done through print functions and in some case where the grade list was complex, by

manually checking that the right grade is being applied.

5.3. The team algorithms

The creation of the team follows a complex algorithms that is outlined in the formalisation. This part of the code was the most challenging one as it dives deep into the object oriented part of the implementation mixed with the lists in which most of the objects are being stored. Groups are formed both in the agenda setting and policy formulation processes. Agents can only be in one group in each of the processes.

5.3.1. Agenda setting

The team algorithm is a long process of steps that the agent has to go through to see if he can join a team, create a team or leave a team.

The first step is to check if the agent has a team and if so to calculate its belonging level. This belonging level is calculated in a specific function that is used throughout the code. This function was checked to make sure that the belonging level is calculated appropriately. This was done by first checking that the same issue is selected by all agents considered. Then the average belief calculated was checked to make sure it adds up. Finally, it was checked that the belonging level calculated from this average is appropriately placed within the agent's attributes.

The second step simple checks whether an agent has enough belonging level to remain in the team or not. If that agent is the leader then the team would have to be disbanded. This was checked by assigning belonging levels lower than 30% to agents to see whether the code worked.

The third step consists of checking whether the agent meets the requirement to be part of the team (if s/he is in a team). Two cases must be distinguished there with the agent being checked being the leader or just being a member. If the agent is the leader and s/he does not belong in the team anymore, the team must be disbanded. If s/he is just a member, then s/he only needs to be removed from the team member list. Throughout the verification of this step, issues arose. The problem was found to be related to the way an agent is removed from the member list. This lead to memory assignment issues within the list members and the code would crash. This has now been fixed and the members are appropriately removed. When a team is disbanded, it is not deleted, it is just removed from the attributes of the agents that were in that team. The main reason to keep the team is for records keeping. This was checked carefully to make sure that the data can be saved when it is collected.

The check of the beliefs is done along two lines depending on whether the team is a problem team or a policy team. The verification here focused on checking that the appropriate equations are being used and the appropriate indexes in the belief hierarchies are selected. In some instances, it was found that the indexes were and this has since been corrected.

After removal of an agent, then the belonging level has to be recalculated. This was checked to make sure that the belonging level of all agents present in the team are upgraded according to the new level.

The fourth step is to check, if the agent is not in a team, whether the agent can join a team that already exists. The verification here is mostly the same as previously as the

requirements are the same. The verification was focused on making sure that the right issues are selected depending on whether the agent is looking at a policy or problem team. And the indexes used were also checked to make sure the right issue is selected.

Finally, the fifth and last step is the creation of a team if the agent still has no team. Again, the requirements here are similar to the ones previously outlined and so is the verification. Additional steps were taken to verify that the resources used are appropriately removed from the agent's attributes. It was also made sure that the appropriate beliefs are used for the creation of the teams as for the first step, partial knowledge is used while for the actual creation check the full beliefs are used. Finally, and this is a big part of the creation of the team, it was checked that overtime there is a contact between agents they provided one another with their beliefs. This was checked and for each of the interactions, there was a check to make sure that the partial knowledge cannot be above one or below minus one.

Checks were also performed on the creation of the teams themselves. It was made sure that the teams are added to the overall list of teams. It was checked that each of the agents considered were added to the list of members in the team. It was made sure that all agents that are part of the team have their attributes updated accordingly and their belonging level checked.

Upon the creation of a team, a shadow network is created. This is in effect the policy network of the team which is created from the network of the team's members. This shadow network created a number of problem as it required the creation of an entirely new network several times leading to a large amount of links. Each of these networks were then stored into arrays associated with the team. This shadow network creation was checked to make sure the right amount of links were added and that they were provided with the correct awareness levels.

Note that these checks were performed for both strategies that are used to create new teams. The checks were fairly similar as the code infrastructure was the same.

5.3.2. Policy formulation

For the policy formulation, the architecture of the code is mostly the same. The verification steps were therefore similar. The main difference as mentioned previously is the change of issues being considered. This was checked thoroughly to make sure the right issues are addressed at this level of the model.

5.4. The coalition algorithms

The coalitions are created following what is outlined in the formalisation. The first problem here is to make sure that the right future coalition leader is being chosen. This is particularly important when one coalition has already been created. The agents must not already be in another coalition so the total amount of awareness needs to be recalculated. This was checked to make sure that no agent is found in more than one coalition at a time.

Then the issue is to check that that the right agents are considered to be inserted in a coalition. This is defined based on the beliefs and based on the policy networks of the lead agent. This is again a question of checking the indexes in such a way that the proper issues are considered by the team leader.

The main difference between the agenda setting and the policy formulation processes is that the issue around which the coalitions are created are different. It was therefore im-

portant to check that the right issue is being considered in both cases.

Checks were also performed on the fact that the coalition must be placed in the coalition list so that it can be recorded. It was also important to check that the agents attributes are appropriately changed when they join a coalition. Finally, it was important to check that the creation of coalition stop at the right amount (in this case less than 10% of the actors are coalition-less).

5.5. The teams actions selection and grading

The actions of the teams are split in two parts: the intra-team actions and the inter-team actions. As mentioned previously in the formalisation, the former are about framing actions within the teams while the latter about actions from the teams on outside agents. These are therefore two very different parts of the code.

The actions were mostly verified in the same way as the actions of the agents. The main difference here was for the inter-team actions which were performed by all actors within the team onto all actors that are within the policy network of the team. This sometimes resulted in hundreds of actions being assessed. It was therefore paramount to rightly pinpoint the right actions, who performed it, onto who and about which issue. This was checked through a multitude print function which are still present in the code. Furthermore, a big problem here was the notation system of Python that considers that the first entry in a list is numbered 0. This leads to multiple attempts were the wrong index was selected. Ultimately, this was fixed and it is now provided with certainty that the right actions are performed.

5.6. The coalitions actions selection and grading

Similarly to the team actions, the coalition actions are modelled on the individual agent actions. They were therefore verified in the same way. The coalition action are much simpler as they are performed by the coalition leader. This reduced the number of actions considered drastically and made it easier to pinpoint which actions should be implemented.

5.7. The awareness decay

The awareness decay is applied at the end of the tick. This was checked by changing the value of decay to this if it works properly. Furthermore, it was checked that the awareness decay pause that is established after an action has been performed worked appropriately. This was done by changing the amount of time after which the awareness decay is paused.

5.8. The initialisation

For the initialisation, all of the inputs that are specified by the modeller are placed into a dictionary. This is then transmitted through the function and classes. To verify this dictionary, each of its entries are checked in the main class from which the model is run and all of its contents are re-assigned to the actual parameters from the model. This dictionary was used to simplify the transmission of the inputs from the initialisation file to the main file. Note that this approach can be used for any future case study.

The initialisation is also a large file that constitutes the first list of agents present in the model and the policy network. This was all checked by using print function to make sure

that the right amount of resources are added or that the right links are created. Furthermore, checks are in place to make sure that the initialised beliefs of all the agents are below one and above minus one.

5.9. The data collection

The data collection is a complex process that uses the architecture of the code used by Project Mesa. The original code used deep copy everywhere to appropriately copy the data into new data framed. However, this takes a very large amount of times within the model implemented (upwards of 4 hours per tick for larger models). It was therefore to change the deep copy approach to a simpler approach using copy.copy. This lead to different problems such as memory assignment issues. Ultimately, it was settled to have a mix of deep copy and copy.copy throughout the code. This was intensely verified to make sure that there are no more memory assignment issues.

6

Further Work

This appendix presents the list of items that has been thought of for further work.

This first list describes the actions that would be required to have a more complete model.

1. Use the appropriate equation for the creation of new policy network links (currently the 0.5 coefficient is missing).
2. Fix of the formalisation for the awareness decay in the case of team and coalition actions.
3. The implementation of the new formalisation
4. The formalisation of the policy broker concept and its implementation.
5. The implementation of the diffusion theory.
6. The implementation of the feedback theory.
7. The implementation of the external party issue selectiveness mentioned in the conceptualisation.
8. The testing of different partial belief hierarchies initialisation methods.
9. The introduction of full knowledge at the principle belief level.
10. The adaption of the code to allow for more or less than three affiliations.
11. The addition of the infrastructure to be able to save what actions are performed by who, with what impact and whom.
12. Provide an analysis of the policy hierarchy results from the three streams model.
13. Introduce a case study and attempt to find a consistent way of designing the connection between the world and policy emergence model along with appropriate initialisation of the policy network.
14. Perform a more complete and consistent experimentation set along with a broader analysis of the results.
15. Introduce a difference between technical and non-technical issues. According to the literature (Nohrstedt and Weible, 2010), this can be important. Actors are more likely to agree on technical issues and disagree on non-technical issues.

This second list describes some extensions or some further work that could be needed to extend the model:

1. Introduce the possibility to have instruments that have an impact over time. This would require the addition of the possibility to grade these instruments against one time impact instruments.

2. The introduction of a policy package tool. This could be an extension where the agents can create their own policy instruments or an extension that uses current models that build policy instruments (there would then only be a need to connect both models).
3. To enrich the model, it could be possible to introduced the three types of subsystem behaviour mentioned in the literature (Nohrstedt and Weible, 2010; Weible, 2008). These are the unitary subsystem, the collaborative subsystem and the adversarial subsystem. The introduction of such differences could affect the behaviour algorithms of the different actors or change specific weights of specific actions within the actors' algorithms.
4. Construct an in-browser live visualisation.
5. Provide a in-browser GUI for the initialisation of the model.

7

Policy Making Theories Concepts

This appendix is a summary of all of the concepts that are mentioned within the theories. It includes their corresponding concepts within the model created in this thesis. When there is no relation, then the concept has not yet been addressed and is therefore not mentioned in the table. Note that a third column is added to signify the policy making theories concepts that have been addressed in the conceptualisation and formalisation but are not yet present within the code.

The concepts with an asterisk are detailed further after the table.

Policy making theories concept	Model	Concep.
The three streams theory		
Fluid participation	✓	✓
Problem preferences	✓	✓
Unclear technology	✗	✗
Policy stream	✓	✓
Value acceptability*	✓	✓
Technical feasibility*	✓	✓
Integration of the instrument	✗	✗
Problem stream	✓	✓
Indicators *	✓	✓
Focusing event	✗	✗
Feedback*	✓	✓
Load	✓	✓
Politics stream	✓	✓
Policy makers	✓	✓
Policy entrepreneurs	✓	✓
Policy entrepreneurs time constraints	✓	✓
Policy window	✓	✓
Team creation criteria	✓	✓
Leading by example	✗	✗
Independent streams	✓	✓
The advocacy framework coalition		
Subsystem	✓	✓

Coalitions	✓	✓
Coalitons influence policy makers	✓	✓
Devil shift	✗	✗
Limited amount of information	✓	✓
Deep core beliefs*	✓	✓
Policy core beliefs	✓	✓
Secondary beliefs	✓	✓
Stable coalitions	✓	✓
Actors show substantial consensus	✓	✓
Secondary before policy core*	✗	✗
Bounded rationality*	✓	✓
Belief system	✓	✓
Coalitions creation criteria	✓	✓
External event	✓	✓
Internal subsystem event	✗	✗
Negotiated agreement	✗	✗
Policy-oriented learning	✓	✓
Policy learning is more likely with moderate level of conflicts	✓	✓
Learning is more likely in a prestigious forum*	✓	✓
Quantitative problems are more conducive to policy learning*	✗	✗
Problems involving natural systems are more conducive to policy learning	✗	✗
Accumulation of technical information does not change the view of opposing coalitions	✗	✗
Administrative agencies advocate for more moderate measures *	✓	✓
Actors within purposive groups are more constrained in their expression beliefs and policy positions than actors from material groups	✗	✗
The diffusion theory		
Leaning mechanism	✓	✓
Imitation	✗	✗
Normative pressure	✓	✓
Competition	✓	✓
Coercion	✓	✓
The feedback theory		
Meaning of citizenship	✓	✓
Form of governance	✗	✗
Power of groups	✓	✓
Definition of policy problems	✓	✓

The resource effect	✓	✓
The interpretive effect	✓	✓
The policy entrepreneurhsip model		
Social acuity	✓	✓
Definition of problems	✓	✓
Policy entrepreneurs should be ready to build teams	✓	✓
Definition of policy problems	✗	✗

Notes concerning the concepts in the advocacy framework coalition:

- The bounded rationality concepts: The agents are not introduced within the model with bounded rationality for say. However, because the agents are included within a large set of agents and each of these agents perfom actions, the overall resulting model can be considered to have agents with boudned rationality.
- Value acceptability, technical feasibility, indicators: these two concepts are not part of the model for say, they can however be incorporated by the modeller in the assessment of the impact of the policy instruments as inputs to the model. In future work, they could be dynamically introduced in the model for the policy instruments. In this way, all policy instruments could be influenced by the agents present in the policy arena.
- Focusing event: Focusing events are not part of the model. However, they can be introduced by the modeller through the use of external events. Depending on the design of the external event, it can act as a focusing event leading to changes in the policy emergence process.
- Feedback: Feedback in the sense of the feedback theory has not been implemented (it was conceptualised and formalised). Feedback is however present through the world simulation in the model.
- Deep core beliefs: They are considered as principle beliefs. Additional layers in the belief hierarchy would be needed to see the use of deep core beliefs which is not excluded by the conceptualisation presented here.
- Secondary before policy core: This assumption is not taken into account in the implementation. However, and this was mentioned within the report, it can be introduced easily.
- Learning is more likely in a prestigious forum: This is not present directly in the model but is introduced through external events which provide a boost in awareness to specific agents participating in a forum.
- Administrative agencies advocate for more moderate measures: This is not excluded, it is dependent on the inputs from the modeller.

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