Appendix A: General model equations

The previous Section (Section 3.3) has described qualitatively the stocks, the flows, the "motivational" variables and all the interconnections of our model (Figure 2). In order to be able to build a simulation tool we have translated there relations into equations.

The main structure of the model is a system of ten non-linear first-order differential equations with stochastic parameters, that depict the integrated evolution of the different "styles" of consumer behaviour. These are:

$$
\begin{cases}
\frac{d(NS_t)}{dt} = -ad(NS_t, t) \\
\frac{d(PS_t)}{dt} = ad(NS_t, t) - sd(PS_t, S_t, SSRm_t, SSRa_t, EA_t, t) + csd(PS_t, S_t, SSRm_t, SSRa_t, EA_t, t) \\
\frac{d(S_t)}{dt} = sd(PS_t, S_t, SSRm_t, SSRa_t, EA_t, t) + cssd(S_t, t) - csd(PS_t, S_t, SSRm_t, SSRa_t, EA_t, t) - ssd(S_t, t) \\
\frac{d(SRRm_t)}{dt} = ssd(S_t, t) - cssd(S_t, t) - asd(SSRm_t, t) \\
\frac{d(SRRa_t)}{dt} = asd(SSRm_t, t) - eead(SSRa_t, t) \\
\frac{d(EA_t)}{dt} = eead(SSRa_t, t) \\
\frac{d(PP_t)}{dt} = ad(NS_t, t) - pd(NS_t, PP_t, t) \\
\frac{d(P_t)}{dt} = pd(NS_t, PP_t, t) \\
\frac{d(PDR_t)}{dt} = ad(NS_t, t) - drd(PDR_t, DR_t) \\
\frac{d(PDR_t)}{dt} = drd(PDR_t, DR_t)
\end{cases}
$$

In the previous system of equations, the state variables are indicated as:

- NS_t is the number of households that, at time *t*, are unable to adopt a 'smart energy behaviour';
- PS_t is the number of households that, at time *t*, are potentially able to adopt the shift consumption behaviour;
- $SSRm_t$ is the number of households that, at time *t*, actually adopt the manual stronger shift and reduction of consumption behaviour;
- $SSRa_t$ is the number of households that, at time *t*, actually adopt the automated stronger shift and reduction of consumption behaviour;
- $SSRa_t$ is the number of households that, at time *t*, actually adopt the energy efficient appliances and automated stronger shift and reduction of consumption behaviour;
- PP_t is the number of households that, at time *t*, are potentially able to adopt the electricity production behaviour;
- P_t is the number of households that, at time *t*, actually adopt the electricity production behaviour;

- PDR_t is the number of households that, at time *t*, are potentially able to adopt the demand responce behaviour;
- DR_t is the number of households that, at time *t*, actually adopt the demand responce behaviour.

We refer to the total population as $TP_t = TP_o$ that is constant.
The flows between stocks are indicated as:

- *ad* - activation dynamics - Flow of new people that have the possibility to change their behaviour (knowledge+technology);
- *sd* - shift dynamics - Flow of new people that decide to change their behaviour by shifting part of their electricity consumption to the lower rate/lower impact segment;
- *csd* - counter shift dynamics - Flow of new people that decide to stop shifting;
- *ssd* - (manual) stronger shift dynamics - Flow of new people that decide to increase their behaviour by manually shifting a larger part of their electricity consumption and reducing wasteful consumption;
- *cssd* - counter (manual) stronger shift dynamics - Flow of new people that decide to stop the manual stronger shift and consumption reduction behaviour;
- *asd* - automated stronger shift dynamics - Flow of new people that decide to increase the effectiveness of their consumption shift/reduction behaviour by using some products or services to automate some actions;
- *eead* - energy efficient appliances dynamics - Flow of new people that decide to buy energy efficient appliances in addition to the previous actions.
- *pd* - production dynamics - Flow of new people that decide to change their behaviour by starting to produce electricity;
- *drd* - demand response dynamics - Flow of new people that decide to change their behaviour by enrolling in demand response programs.

Appendix B reports the analytical study of the equilibrium of the system, showing that a unique theoretical equilibrium exists. Appendix C reports instead the detailed description of the particular implementation of this model in the case of Italy.

Appendix B: Theoretical study of the equilibrium

Our system of equations is too complex to be able to solve it to find an analytical solution. Nevertheless, it is possible to prove theoretically the existence, and uniqueness, of the equilibrium and to study its stability.
This is useful to prove the coherence between the numerical simulations that will be described in the following Section (Section 4.1) and the theoretical properties of the system.
To find the equilibrium and to study its stability characteristics, we have had to simplify the model slightly, by:

- removing the time dependency of the variables - in order to have an autonomous system of equations, even if our model has proved to be at least asymptotically autonomous, as time-varying parameters converge to constants.
- simplifying the step functions, in order for the values to be differentiable;

For this kind of analysis, we have collapsed all the variables into time-varying, time-invariant, and stock-variable dependent terms. We have solved the system so that the above derivatives are contemporaneously set to zero and found the following equilibrium solutions:

$$\begin{cases} NS_t = 0 \\ PS_t = 0 \\ S_t = 0 \\ SSRm_t = 0 \\ SSRa_t = 0 \\ EA_t = \overline{EA_t} \\ PDR_t = 0 \\ DR_t = \overline{DR_t} \\ PP_t = 0 \\ P_t = \overline{P_t} \end{cases}$$

Moreover, it can be proved that the following conservation laws hold:

$$\frac{dNS_t}{dt} + \frac{dPS_t}{dt} + \frac{dS_t}{dt} + \frac{dSSRm_t}{dt} + \frac{dSSRa_t}{dt} + \frac{dEA_t}{dt} = 0 \qquad \forall t$$

$$\Rightarrow \frac{d(NS_t + PS_t + S_t + SSRm_t + SSRa_t + EA_t)}{dt} = 0 \qquad \forall t$$

$$\Rightarrow NS_t + PS_t + S_t + SSRm_t + SSRa_t + EA_t = cost \qquad \forall t$$

$$\frac{dNS_t}{dt} + \frac{dPDR_t}{dt} + \frac{dDR_t}{dt} = 0 \qquad \forall t$$

$$\Rightarrow \frac{d(NS_t + PDR_t + DR_t)}{dt} = 0 \qquad \forall t$$

$$\Rightarrow NS_t + PDR_t + DR_t = cost \qquad \forall t$$

$$\forall t$$

$$\Rightarrow \frac{d(NS_t + PP_t + S_t + P_t)}{dt} = 0 \qquad \forall t$$

$$\Rightarrow NS_t + PP_t + P_t = cost \qquad \forall t$$

Given the above conservation laws and the initial conditions (below), it straighforward to identify the equilibrium points:

$$\begin{cases} NS(0) = 13.4 * 10^6 \\ PS(0) = 6.7 * 10^6 \\ S(0) = 0 \\ SSRm(0) = 0 \\ SSRa(0) = 0 \\ EA(0) = 0 \\ PDR(0) = 6.7 * 10^6 \\ DR(0) = 0 \\ PP(0) = 6.7 * 10^6 \\ P(0) = 0 \end{cases} \Rightarrow \begin{cases} \overline{EA} = NS(0) + PS(0) = 20.1 * 10^6 \\ \overline{DR} = NS(0) + PDR(0) = 20.1 * 10^6 \\ \overline{P} = NS(0) + PP(0) = 20.1 * 10^6 \end{cases}$$

The system admits ∞^3 equilibrium points that are univocally determined by the initial conditions.
To investigate the stability of the equilibrium points, we have linearised the system and computed the eigenvalues of the Jacobian Matrix; these turn out to be all negative except for three that are equal to zero, confirming the stability of all equilibrium solutions.

In the current version of the model all classes, except for the last ones, are expected to get empty as t increases. If future empirical evidence will contradict this asymptotic behaviour, frictions could be added to the model, i.e., replacing, where appropriate, $Stock_i(t)$ with $Stock_i(t)-\varphi_i$ in the right-hand-side terms of the differential equations of system **Errore. L'origine riferimento non è stata trovata.**. Though, these would only mean that a certain amount of the stock of households would remain in the various boxes, generating an equilibrium of the type:

$$\begin{cases} \overline{NS} = \varphi_{NS} \\ \overline{PS} = \varphi_{PS} \\ \bar{S} = \varphi_{S} \\ \overline{SSRm} = \varphi_{SSRm} \\ \overline{SSRa} = \varphi_{SSRa} \\ \overline{EA} = NS(0) + PS(0) - \sum_i \varphi_i \\ \overline{PDR} = \varphi_{PDR} \\ \overline{DR} = NS(0) + PDR(0) - \sum_i \varphi_i \\ \overline{PP} = \varphi_{PP} \\ \bar{P} = NS(0) + PP(0) - \sum_i \varphi_i \end{cases}$$

Note that some of the above φ_i could be zero.

Appendix C: Description of the model applied to Italy

In this section we present in detail all the auxiliary variables and related equations that have been used to simulate our first implementation of the model focusing on Italy. This particular implementation is meant to be just a first attempt to study the evolution of a very interesting and important phenomenon. We do not claim this model to be exhaustive nor conclusive, but rather a compromise between the interest in a quantitative analysis and the data availability at this very primitive stage.
The *ad* flux of Equations (**Errore. L'origine riferimento non è stata trovata.**) and (**Errore. L'origine riferimento non è stata trovata.**) has been detailed as follows:

$$ad(NS_t,t) = ma(t) \cdot NS_t \cdot qi \,,$$

$$ma(t) = \min(0.33 \cdot t, 1) \,,$$

with *ma* - meter activation - being the percentage of smart meters that are activated by time t, and *qi* - initial-information quality - being the percentage of people that take notice of the information provided, i.e., that know they have new options, equal to 0.78. These parameters have been estimated from the activation rate of 2010 (AEEG, 2011b) and on the basis of the percentage of consumers that state to be satisfied of the comprehensibility of the display on the smart meter, taken as a lower bound for the households aware of the change and able to access the additional information (ISTAT, 2011).
The numeric value of the *sd* flow represents the number of households that move to the 'shift' stock in an infinitesimal unit of time. The households that change box/behaviour are those that are sensitive to at least one of the motivational drivers (economic and/or ethic). This is, formally, the union of the households that are sensitive to economic and/or environmental and social issues. To calculate this quantity it would be necessary to know the joint-distribution of these two motivational drivers among the households. Unfortunately, this value is not available in the literature. Values for the single effects are instead available, but for these to be of use - and avoid double-counting - it is necessary to also know the size of the intersection, i.e., the number of households that are sensitive to both stimuli. The size of

the intersection can be calculated from the single values only if one of the following three assumptions holds:

- *disjunction* (i.e., households are sensitive to one or the other stimulus, but never to both). In this case, the measure of the union is the sum of the two individual values;
- *inclusion* (i.e., being sensitive to one stimulus (the smallest) implies being sensitive also to the other). In this case, the the measure of the union is the maximum between the two single values;
- *independence* (i.e., the proportion of households that are sensitive to the economic motivation is identical among the households that are interested or not interested in the environmental motivation, and viceversa). In this case, the measure of the union is the sum of the two values minus their product).

The first two assumptions are quite extreme and certainly not realistic, the third is an intermediate case and therefore might be closer to the real situation. For this reason, we introduce in our model the third assumption, and in order partially overcome this approximation, we have: (*i*) stratified the population for economic welfare and assumed independence just within the stratum, and (*ii*) performed a multivariate sensitivity analysis of these (and other) values.

The *sd* flux depends on all the active consumption management stocks, therefore, to simplify notation we indicate as CM_t the set of the variables S_t, $SSRm_t$, $SSRa_t$, and EA_t. Indeed, the *sd* flux of Equations (**Errore. L'origine riferimento non è stata trovata.**) and (**Errore. L'origine riferimento non è stata trovata.**) has been detailed as follows:

$$sd(PS_t,CM_t,t)=\left[em(CM_t,t)+esm(CM_t,t)-em(CM_t,t)\cdot esm(CM_t,t)\right]\cdot(1+ea(CM_t))\cdot PS_t ,$$

where *em* - economic motivation - is the percentage flow of people that decide to shift because of economic reasons (without the effect of ease) and *esm* - environmental social motivation - is the percentage flow of people that decide to shift because of environmental/social reasons (without the effect of ease).

The auxiliary variable *ea* - ease - represents a reinforcing effect that "ease in shifting" has on the decision to shift and is defined as:

$$ea(CM_t)=\frac{1}{3}\cdot mk(CM_t) ,$$

where *mk* - available market - represents the percentage of people that have already changed behaviour by starting to actively manage their electricity consumption ($(S_t+SSRm_t+SSRa_t+EA_t)/TP_o$) and that therefore constitute potential customers for firms interested in producing related goods and services.

The economic and ethical (environmental/social) motivation percentage flows are constituted by the percentage of households, that in the unit of time, change their behaviour due to some information, channeled through one of informational vectors of model. Again, to avoid double counting households that are sensitive to more than one informational channel, we have assumed the - less extreme - hypothesis of independence. The percentage flows *em* and *esm* are, consequently, defined as:

$$em(CM_t,t)=1-(1-ic_e)(1-dsm_e)(1-mc_e)(1-adv_e)(1-wom_e) ,$$

$$esm(CM_t,t)=1-(1-ic_{es})(1-mc_{es})(1-wom_{es}) ,$$

where ic_e (information campaigns effect), dsm_e (demand side management effect), mc_e (media coverage effect), adv_e (advertising effect), and wom_e (word of mouth effect), are the percentage of people that change behaviour (shift) because of info-campaigns / demand-side-management / media-coverage / adversing / word-of-mouth on the economic benefits of the new behavioural options induced by smart-metering. Similarly, ic_{es}, mc_{es}, and wom_{es} are defined for the environmental and social benefits. More specifically, they are defined as:

$$ic_e(CM_t) = \begin{cases} \eta_{ic} \cdot ies \cdot \sqrt{\frac{pg}{pg_o}} & for\ mk_t(CM_t)<0.5 \\ 0 & for\ mk_t(CM_t)\geq 0.5 \end{cases},$$

$$ic_{es}(CM_t) = \begin{cases} \eta_{ic} \cdot iee & for\ mk_t(CM_t)<0.5 \\ 0 & for\ mk_t(CM_t)\geq 0.5 \end{cases},$$

$$dsm_e = \eta_{dsm} \cdot ies \cdot \sqrt{\frac{pg}{pg_o}},$$

$$mc_e(CM_t) = \eta_{mc}(CM_t) \cdot ies \cdot \sqrt{\frac{pg}{pg_o}},$$

$$mc_{es}(CM_t) = \eta_{mc}(CM_t) \cdot iee,$$

$$adv_e(CM_t) = \eta_{adv}(CM_t) \cdot ies \cdot \sqrt{\frac{pg}{pg_o}},$$

$$wom_e(CM_t) = \eta_{wom}(CM_t) \cdot ies \cdot \sqrt{\frac{ag(CM_t)}{ag_o}},$$

$$wom_{es}(CM_t) = \eta_{wom}(CM_t) \cdot iee.$$

The quantities η_j - effectiveness of the *j*th information channel - represent the effectiveness of the informational channels on households that are interested in their content. Instead, the variables *ies* - interest in economic savings - and *iee* - interest in the environmental effects - represent the percentage of households (for each segment of the population) that are interested in economic savings and the percentage of households that are interested in the environmental effects of their actions (and act consequently), respectively. We have estimated these values analysing the micro data of ISTAT (2011), calculating the joint distribution of these interests and the welfare condition. More specifically, as a proxy for the share of households interested in the environment we have calculated the distribution of people that declare that environmental problems are among the three worst problems of the country. As a proxy for the share of households interested in economic savings, we have considered the percentage of consumers that have changed their electricity provider or decided not to change for lack of information on the savings or for lack of actual savings, conditioned to knowing of the possibility to do so.

For the economic motivation, we have also added a reinforcing/reducing effect related to the potential economic gain - *pg* - (or average economic gain - *ag* - in the case of personal communication) associated with the behavioural change, that is related to the price difference in the tariff for the various daily time-segments (*td* - tariff difference). The values of pg_o and ag_o are those of the reference situation. More specifically, these quantities are defined as:

$$pg = msl \cdot td,$$

$$ag(CM_t) = asl(CM_t) \cdot td,$$

with

$$td=0.1,$$

$$msl{=}0.5\ ,$$

$$asl(CM_t){=}\frac{(\Theta_S{\cdot}S_t{+}\Theta_{SSRm}{\cdot}SSRm_t{+}\Theta_{SSRa}{\cdot}SSRa_t{+}\Theta_{EA}{\cdot}EA_t)}{S_t{+}SSRm_t{+}SSRa_t{+}EA_t}\ .$$

In this version of the model *td* is not time-dependent as it has not changed very much in the first years of the introduction of the compulsory differentiated tariff, nevertheless the model can be updated once the tariff-difference will be varied.We define the *msl* - maximum shift level - as the maximum percentage of electricity consumption that can be managed by the residential consumer from Molderink *et al.* (2009) and Block *et al.* (2008). The quantity *asl* - average shift level - is, instead, the average of the percentage savings that are incurred (and reported) by the households that are actively managing their electricity consumption, where Θ_k is the percentage saving for the *k*th behavioural style.

As described in Section 3.3, the information-campaign effect and the demand-side-management effect are exogenous stimuli that trigger the first-adopters; the central values of the relative parameters η_{ic} and η_{dsm}, used in our simulations, are: 0.05 and 0.074. These values are taken from Snyder & Hamilton (2002), Haug (2004), Snyder (2007) and adapted from eMeter (2010). Note that we estimate these parameters from the literature by assuming that the percentages referring to people can be transferable to the household unit/level.

Moreover, we assume that while demand side management policies can continuously be improved, information campaigns cease once a certain level of population has adopted the targeted behaviour. The central value of this level is assumed to be 50%. The efficiency parameters of the remaining three effects, that are endogenous in the model and arise only once (and proportionally) there are already some adopters of the behaviour, are modelled as follows:

$$\eta_{mc}(CM_t) = \begin{cases} \frac{0.05}{0.3}{\cdot}mk(MC_t) & for\ mk(CM_t){<}0.3 \\ 0.05 & for\ mk(CM_t){\geq}0.3 \end{cases}\ ,$$

$$\eta_{adv}(CM_t) = \begin{cases} \frac{0.016}{0.3}{\cdot}mk(MC_t) & for\ mk(CM_t){<}0.3 \\ 0.016 & for\ mk(CM_t){\geq}0.3 \end{cases}\ ,$$

$$\eta_{wom}(CM_t) = c{\cdot}i{\cdot}mk(MC_t)\ ,$$

where *c* is number of contacts that a household has in the unit of time - i.e., number of households to which a "smart-energy behaving household" talks about its benefits - and *i* is their relative infectivity, i.e., the percentage of people that are affected by the contact and decide to act consequently. The values for these two parameters (c=19 and i=0.02) and the numerical values in the above equations for η_{mc} and η_{adv} are adapted from the literature (Sultan *et al.*, 1990; Yoo *et al.*, 2010; Haug, 2004). In particular, for the media-coverage case the values are taken from the literature on a wide interest topic like health. Assuming that health is of interest to the whole population, we use this literature value as a proxy for the effectiveness of media coverage on interested population. Recall that the percentages of households interested in economic savings and/or in the environmental effects - namely, *iee* and *ies*, are calculated from ISTAT (2011).

The counter-flow *csd* is defined as the number of people that decide to stop shifting after having tried this behaviour for one year, more specifically:

$$csd_t(CM_{t-1},t{-}1){=}op{\cdot}sd_{t-1}(CM_{t-1},t{-}1)\ ,$$

with *op* being the opt-out percentage, equal to 0.005.

Once the household has entered the active consumption management macro-box, by starting with the soft shifting behaviour, it can increase its effort and effectiveness in achieving economic savings and benefits for the environment and society by moving along the other sub-boxes. The fluxes are defined as follows:

$$ssd_t(S_t,SSRm_t)=\gamma_{ssd}\cdot S_t \ ,$$

$$cssd_t(S_{t-1},SSRm_{t-1})=op\cdot ssd_{t-1}(S_{t-1},SSRm_{t-1}) \ ,$$

$$asd_t(SSRm_t,SSRa_t)=\left(\gamma_{asd}+c\cdot i\cdot\frac{SSRa_t}{TP_o}\right)\cdot(1+\uparrow\cdot\eta_{adv}(CM_t))\cdot SSRm_t \ ,$$

$$eead_t(SSRa_t,EA_t)=\left(\gamma_{eead}+c\cdot i\cdot\frac{EA_t}{TP_o}\right)\cdot(1+\uparrow\cdot\eta_{adv}(CM_t))\cdot SSRa_t \ .$$

We are not able, at present, to estimate the γs from the literature as the phenomenon is at its primitive stages, therefore we choose the following central values 0.2, 0.1 and 0.05, but we choose a probability distribution with a high variance. Note also that here we model advertising as having a strengthening effect on adoption as found in Haug (2004). Indeed, we multiply η_{adv} by a term ↑ ($\uparrow=\frac{0.09}{0.016}$) so that this product's saturation level is 0.09.

As described in Section 3.3, the demand response dynamic - *drd* - is modelled as having similar motivational channels as the active consumption management case, though the reduced comfort in the curtaillement periods has lead us to reduce its diffusion speed, compared to that of the soft shifting behaviour. Indeed,

$$drd(PDR_t,DR_t)=\left[em_{dr}(DR_t)+esm_{dr}(DR_t)-em_{dr}(DR_t)\cdot esm_{dr}(DR_t)\right]\cdot dsc\cdot PDR_t \ ,$$

$$em_{dr}(DR_t)=1-(1-ic_{e,dr})(1-dsm_{e,dr})(1-mc_{e,dr})(1-adv_{e,dr})(1-wom_{e,dr}) \ ,$$

$$esm_{dr}(DR_t)=1-(1-ic_{es,dr})(1-mc_{es,dr})(1-wom_{es,dr}) \ ,$$

$$ic_{e,dr}(DR_t)=\begin{cases}\eta_{ic}\cdot ies\cdot\sqrt{\frac{eg(t)}{eg_o}} & for\ DR_t<0.5\\ 0 & for\ DR_t\geq 0.5\end{cases} \ ,$$

$$ic_{es,dr}=\begin{cases}\eta_{ic}\cdot iee & for\ DR_t<0.5\\ 0 & for\ DR_t\geq 0.5\end{cases} \ ,$$

$$dsm_{e,dr}(t)=\eta_{dsm}\cdot ies\cdot\sqrt{\frac{eg(t)}{eg_o}} \ ,$$

$$mc_{e,dr}(DR_t)=\eta_{mc,dr}(DR_t)\cdot ies\cdot\sqrt{\frac{eg(t)}{eg_o}} \ ,$$

$$mc_{es,dr}(DR_t))=\eta_{mc,dr}(DR_t)\cdot iee \ ,$$

$$adv_{e,dr}(DR_t)=\eta_{adv,dr}(DR_t)\cdot ies\cdot\sqrt{\frac{eg(t)}{eg_o}} \ ,$$

$$wom_{e,dr}(DR_t) = \eta_{wom,dr}(DR_t) \cdot ies \cdot \sqrt{\frac{eg(t)}{eg_o}} ,$$

$$wom_{es,dr}(DR_t) = \eta_{wom,dr}(DR_t) \cdot iee ,$$

$$\eta_{mc,dr}(DR_t) = \begin{cases} \frac{0.05}{0.3} \cdot \frac{DR_t}{TP_o} & for\ DR_t < 0.3 \\ 0.05 & for\ DR_t \geq 0.3 \end{cases} ,$$

$$\eta_{adv,dr}(DR_t) = \begin{cases} \frac{0.016}{0.3} \cdot \frac{DR_t}{TP_o} & for\ DR_t < 0.3 \\ 0.016 & for\ DR_t \geq 0.3 \end{cases} ,$$

$$\eta_{wom,dr}(DR_t) = c \cdot i \cdot \frac{DR_t}{TP_o} ,$$

where *dsc* - discomfort - is the parameter that reduces the diffusion rate. No literature quantitative has been found on this topic, therefore we have chosen a hypothetical conservative central value of 1/3 and included such parameter in the stochastic analysis.

For the production dynamic branch we have decided to change approach (at least in this first modelling attempt) and model it so that it replicates estimates of distributed generation diffusion from the literature, due to the fact that some specific data and estimates are available.

Model improvements and refinements would be certainly possible but at the moment there are two main obstacles, namely the very early primary stages of the process and the commercial interest in the data necessary that has made it not possible for us to retrieve some important data for the model calibration. This will be possible once initial data will be gathered and made available.

For what concerns the electricity production branch of the model, although the problem can be theoretically approached in a similar way than for the other branches, in this case, the phenomenon is not at such early stages and, therefore, it is possible to extrapolate some trends from the data. We choose to do so as, currently, data on the time dynamics is more available in the literature compared to data for estimating the parameters that define the different cognitive decisions of the consumers when considering if and when to become prosumers. For the other two branches of the model we have considered the modelling approach more appropriate as the data to extrapolate the time dynamics of adoption have not yet been collected or disclosed. The only results available are those of pilot studies that we use for estimating the impacts of consumer adoption, but that in most case concern samples of people that voluntarily decide to take part to the experiment.

Concerning the Monte Carlo approach, the values of the parameters have been extracted from beta-distributions between [0;1] for the following parameters:

- *qi* - initial-information quality;
- *ies* - interest in economic gain;
- *iee* - interest in environmental effects;
- *td* - tariff-difference;
- available market threshold value;
- available market threshold value for information campaigns;
- η_{dsm} - Demand-Side-Management efficacy;

- η_{ic} - information-campaigns efficacy;
- η_{mc} - media-coverage efficacy;
- η_{adv} - advertisement efficacy;
- *ea* - ease parameter;
- *i* - infectivity;
- *op* - opt-out percentage;
- γ_{ssd} - SSRm flow parameter;
- γ_{asd} - SSRa flow parameter;
- γ_{eead} - EEA flow parameter;
- *dsc* - discomfort parameter;
- $\eta_{dsm,dr}$ - Demand-Side-Management efficacy for Demand Response;

adopting as the mean value the one found in the literature and 0.01 as the standard deviation. A graph depicting the sample densities is reported in Appendix E. We have also made the *c* - number of contacts - parameter stochastic, though we used a Poisson probability distribution with mean and variance equal to 19. We obtain 2500 solutions associated with 2500 possible realizations of the vector of the parameter values. These results have been analysed using the statistical environment R (R Development Core Team, 2010).

Appendix D - Sensitivity Analysis

7.1 Sensitivity Analysis

An additional interesting analysis is to investigate, at a first order approximation level, the ultimate effect of each single model parameter on the dynamic of the system and, in particular, on the impacts that can be generated on residential consumption (i.e., Aggregate Shift, Aggregate Reduction, Demand Response adoption).

This sensitivity analysis is carried out by means of OLS regression. Figures 14, 15, 16, report the scatter plots of Aggregate Shift, Aggregate Reduction, and Demand Response adoption in 2020[7] versus the corresponding values of the model parameters, for the 2500 simulations. Point colours are the same as those used for the simualtion curves of the Figures of Section 4.1. Moreover, in each scatter plot the corresponding univariate-regression line is depicted with the corresponding R^2 index. From these plots it is already possible to identify some strong positive dependencies (e.g., Infectivity, Contacts, other informational channels efficacy, etc.) and some negative ones (e.g., opt-out percentage).

A more precise analysis of these dependencies can be carried out by looking at Tables 17, 18, 19 , where for each model parameter some indexes of the corresponding uni-variate regression are reported:

[7] This year has been chosen as a reference year for the sensitivity analysis as it is one of the years in which the differences among the 2500 simulations is stronger

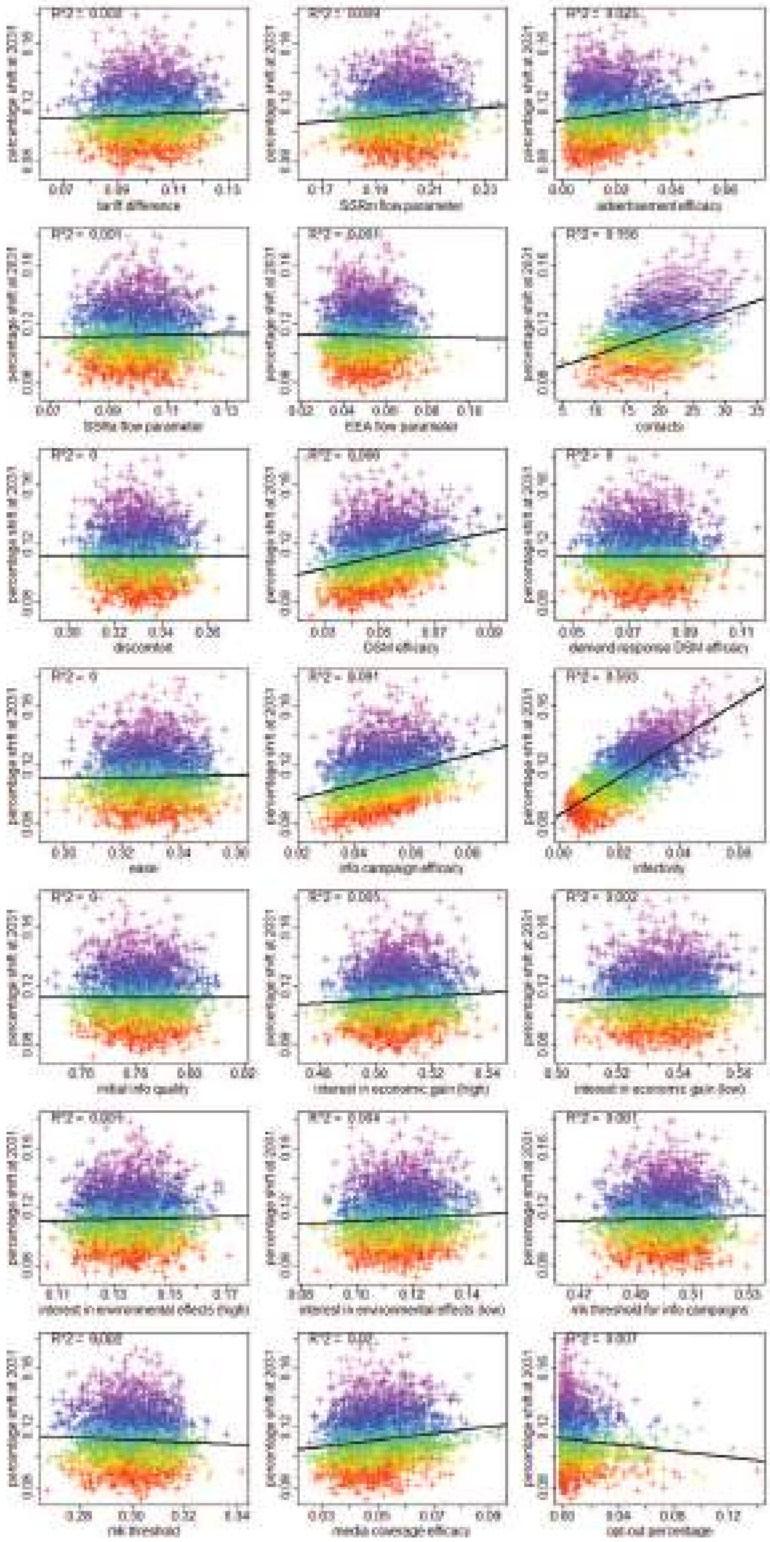

Figure 14: Scatter plot of Aggregate Consumption Shift vs. model parameters - univariate regression

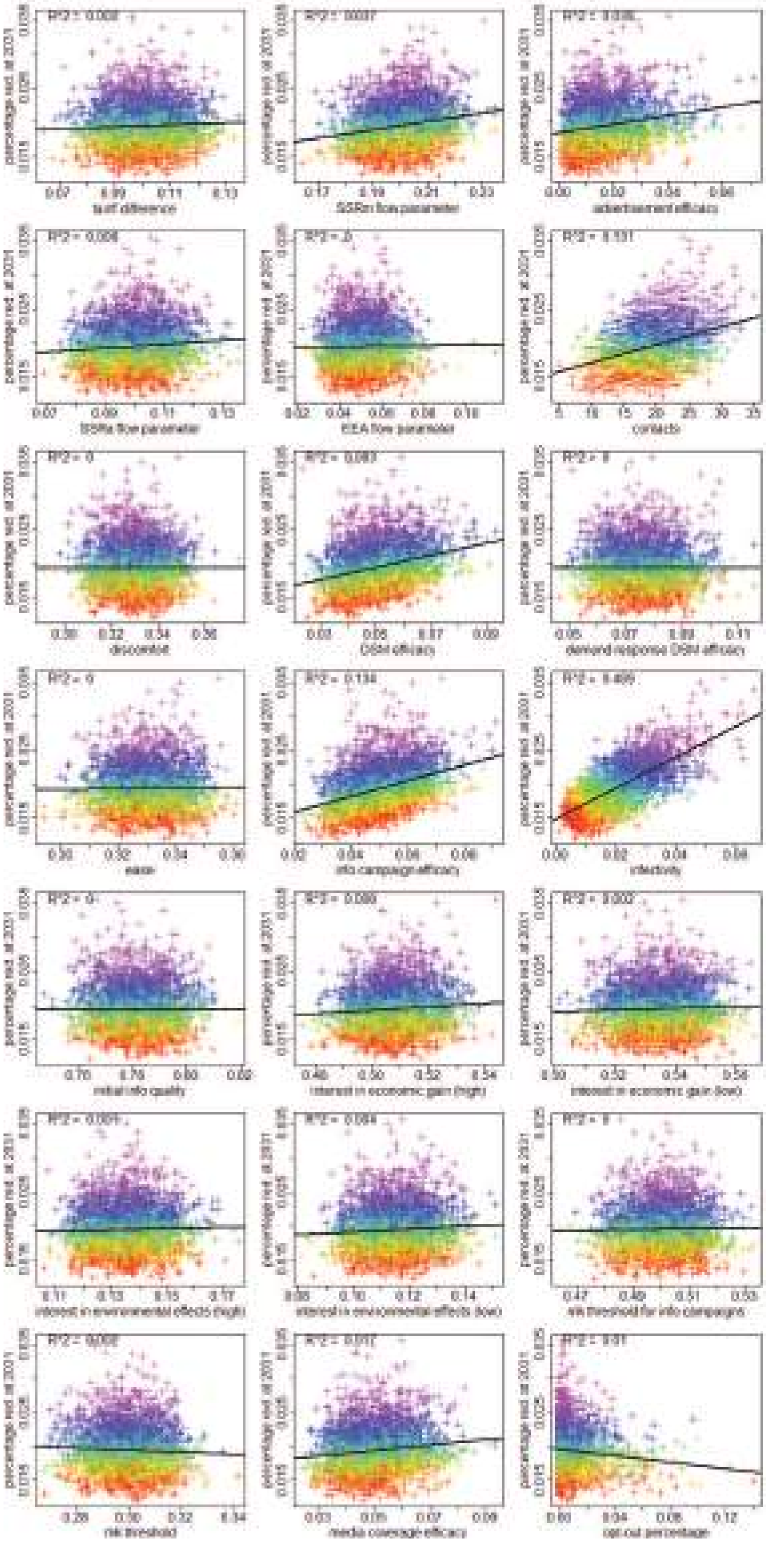

Figure 15: Scatter plot of Aggregate Consumption Reduction vs. model parameters - univariate regression

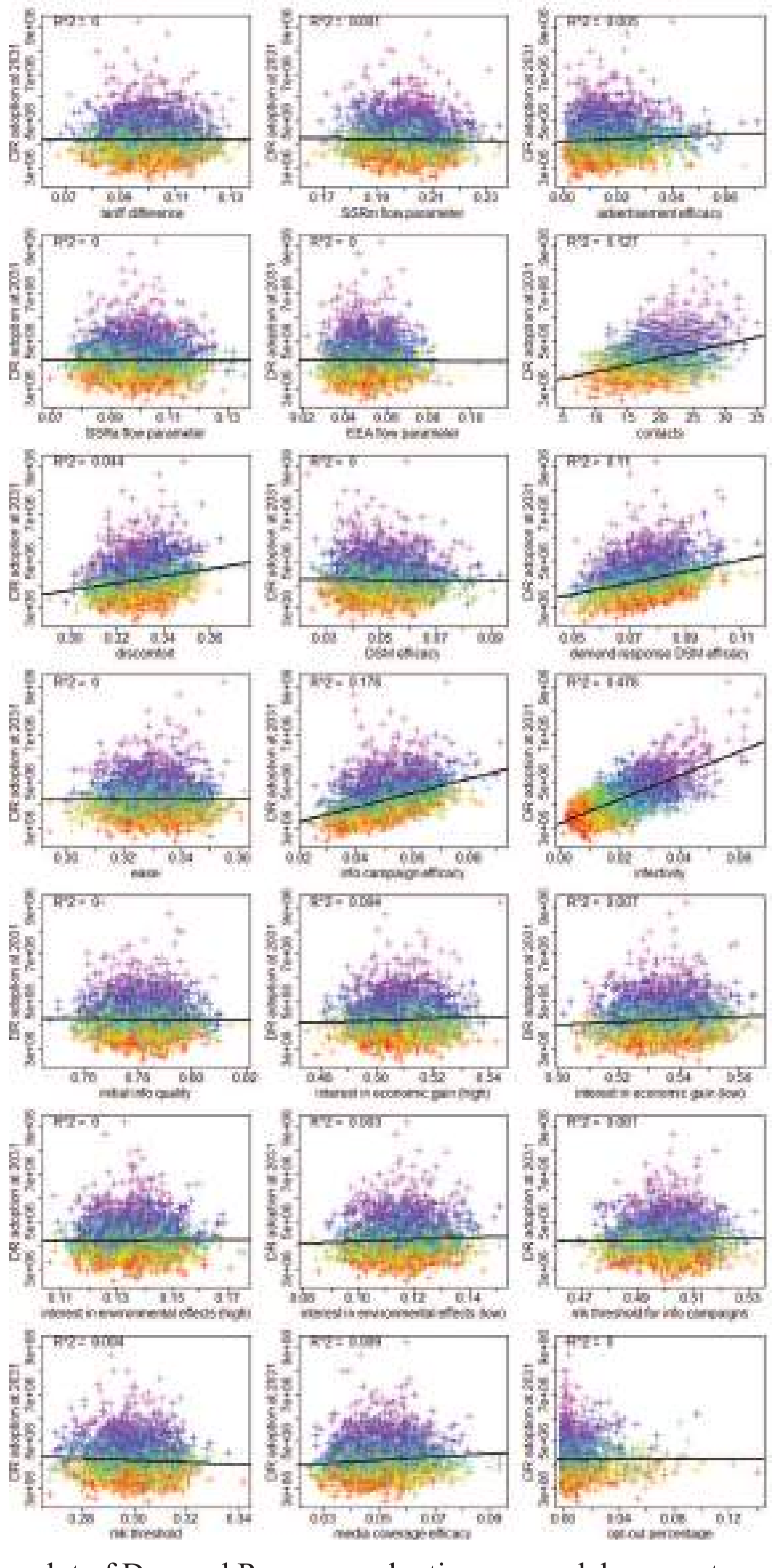

Figure 16: Scatter plot of Demand Response adoption vs. model parameters - univariate regression

Model Parameter	β est.	β est. std. dev.	t-statistic	significance
infectivity	2.27E-01	4.65E-03	4.87E+01	***
information-campaigns efficacy	1.15E-01	5.87E-03	1.96E+01	***
contacts	2.62E-04	1.35E-05	1.94E+01	***
demand-side-management efficacy	9.00E-02	5.99E-03	1.50E+01	***
advertisement efficacy	6.28E-02	6.28E-03	1.00E+01	***
SSRm flow parameter	6.17E-02	6.26E-03	9.85E+00	***
media-coverage efficacy	4.00E-02	6.14E-03	6.52E+00	***
opt-out percentage	-2.40E-02	4.79E-03	-5.02E+00	***
SSRa flow parameter	2.85E-02	6.53E-03	4.37E+00	***
interest in economic gain	2.45E-02	6.41E-03	3.82E+00	***
interest in environmental effects 0	2.07E-02	6.29E-03	3.29E+00	**
available market threshold value	-1.52E-02	6.24E-03	-2.43E+00	*
interest in economic gain 0	1.51E-02	6.36E-03	2.37E+00	*
tariff-difference	1.41E-02	6.20E-03	2.28E+00	*
interest in environmental effects	8.07E-03	6.28E-03	1.28E+00	
ease parameter	6.71E-03	6.46E-03	1.04E+00	
available market threshold value for information campaigns	6.35E-03	6.50E-03	9.77E-01	
EEA flow parameter	4.08E-03	6.39E-03	6.39E-01	
demand-side-management efficacy for demand response	2.52E-03	6.44E-03	3.91E-01	
discomfort parameter	-2.44E-03	6.28E-03	-3.89E-01	
initial-information quality	1.18E-03	6.39E-03	1.84E-01	

Figure 17: Summary indexes of Aggregate Consumption Shift vs. model parameters - univariate regression

Model Parameter	β est.	β est. std. dev.	t-statistic	significance
infectivity	2.27E-01	4.65E-03	4.87E+01	***
information-campaigns efficacy	1.15E-01	5.87E-03	1.96E+01	***
contacts	2.62E-04	1.35E-05	1.94E+01	***
demand-side-management efficacy	9.00E-02	5.99E-03	1.50E+01	***
advertisement efficacy	6.28E-02	6.28E-03	1.00E+01	***
SSRm flow parameter	6.17E-02	6.26E-03	9.85E+00	***
media-coverage efficacy	4.00E-02	6.14E-03	6.52E+00	***
opt-out percentage	-2.40E-02	4.79E-03	-5.02E+00	***
SSRa flow parameter	2.85E-02	6.53E-03	4.37E+00	***
interest in economic gain	2.45E-02	6.41E-03	3.82E+00	***
interest in environmental effects 0	2.07E-02	6.29E-03	3.29E+00	**
available market threshold value	-1.52E-02	6.24E-03	-2.43E+00	*
interest in economic gain 0	1.51E-02	6.36E-03	2.37E+00	*
tariff-difference	1.41E-02	6.20E-03	2.28E+00	*
interest in environmental effects	8.07E-03	6.28E-03	1.28E+00	
ease parameter	6.71E-03	6.46E-03	1.04E+00	
available market threshold value for information campaigns	6.35E-03	6.50E-03	9.77E-01	
EEA flow parameter	4.08E-03	6.39E-03	6.39E-01	
demand-side-management efficacy for demand response	2.52E-03	6.44E-03	3.91E-01	
discomfort parameter	-2.44E-03	6.28E-03	-3.89E-01	
initial-information quality	1.18E-03	6.39E-03	1.84E-01	

Figure 18: Summary indexes of Aggregate Consumption Reduction vs. model parameters - univariate regression

Model Parameter	β est.	β est. std. dev.	t-statistic	significance
infectivity	5.10E+07	1.07E+06	4.77E+01	***
information-campaigns efficacy	3.03E+07	1.30E+06	2.33E+01	***
contacts	5.88E+04	3.08E+03	1.91E+01	***
demand-side-management efficacy for demand response	2.42E+07	1.38E+06	1.75E+01	***
discomfort parameter	1.50E+07	1.40E+06	1.08E+01	***
media-coverage efficacy	6.68E+06	1.40E+06	4.75E+00	***
interest in economic gain 0	6.09E+06	1.44E+06	4.22E+00	***
advertisement efficacy	5.22E+06	1.45E+06	3.59E+00	***
interest in economic gain	4.42E+06	1.46E+06	3.03E+00	**
available market threshold value	-4.29E+06	1.42E+06	-3.02E+00	**
interest in environmental effects 0	4.11E+06	1.43E+06	2.87E+00	**
SSRm flow parameter	-2.08E+06	1.45E+06	-1.43E+00	
available market threshold value for information campaigns	1.87E+06	1.48E+06	1.27E+00	
demand-side-management efficacy	-1.14E+06	1.42E+06	-7.99E-01	
initial-information quality	-1.14E+06	1.45E+06	-7.84E-01	
EEA flow parameter	-9.52E+05	1.45E+06	-6.55E-01	
interest in environmental effects	8.22E+05	1.43E+06	5.75E-01	
ease parameter	7.77E+05	1.47E+06	5.28E-01	
SSRa flow parameter	-7.87E+05	1.49E+06	-5.28E-01	
opt-out percentage	5.59E+05	1.10E+06	5.10E-01	
tariff-difference	-3.85E+05	1.41E+06	-2.73E-01	

Figure 19: Summary indexes of Demand Response adoption vs. model parameters - univariate regression

estimate of the β coefficient, its standard deviation, t-statistic, significance of the t-test. In these tables, the model parameters are ordered accordingly to their significance. The corresponding ranking can be considered as a marginal sensitivity ranking.
More interestingly for extracting policy implications is a ranking based on a *ceteris paribus* sensitivity analysis, since in real-life applications policy-makers may be interested in knowing the effect of varying the level of one parameter keeping the other unchanged. This kind of sensitivity has been carried out by means of a multivariate linear regression. This regression model allows to overcome the masking effect due to the high number of regressors. Figures 20, 21, 22, report the scatter plots of the residuals of the regression of Aggregate Shift, Aggregate Reduction, and Demand Response adoption with respect to all model parameters, except for the one under examination, vs. the value of the same parameter.
In Tables 23, 24, 25 the results of the regression are reported. Also in these tables, the model parameters are ordered accordingly to their significance. As expected, due to the unmasking effect, more variables turn out to be significant. For this type of linear regression model, it is known that the regression coefficients represent the average effects on the response associated with a unit increment of the regressor, if the other regressors remain unaffected. Therefore, for example, we can expect a percentage point increment in the word of mouth infectivity to generate an increment in the aggregate consumption shift at 2020 of 1.28 percentage points, if the other model parameters remain unaffected, and so on.
Our results show that for the Shifting behaviour, infectivity is by large the most effective parameter, followed by contacts, information-campaign efficacy and demand-side-management efficacy. The parameters relative to the Demand Response and *eea* are uninfluent, coherently with the model configuration.
For consumption reduction, we have very similar results. Note that here *eea* is significant as there is a considerable difference between the redution level of the SSRa box compared to that of the EEA box.
For the demand response adoption, infection confirms its primary role; information-campaign efficacy, specific demand-side-management efficacy, contacts and the discomfort level due to load curtailments are also important. Also here, the parameters that result not significant are those that do not interact with this branch of the model.
In synthesis, even if in all cases all the parameters relevant to the model branch result influent, we can see hoe the most important parameters are those that govern the word of mouth effect and the other informational channels, suggesting that these should be the ones targeted by policies.

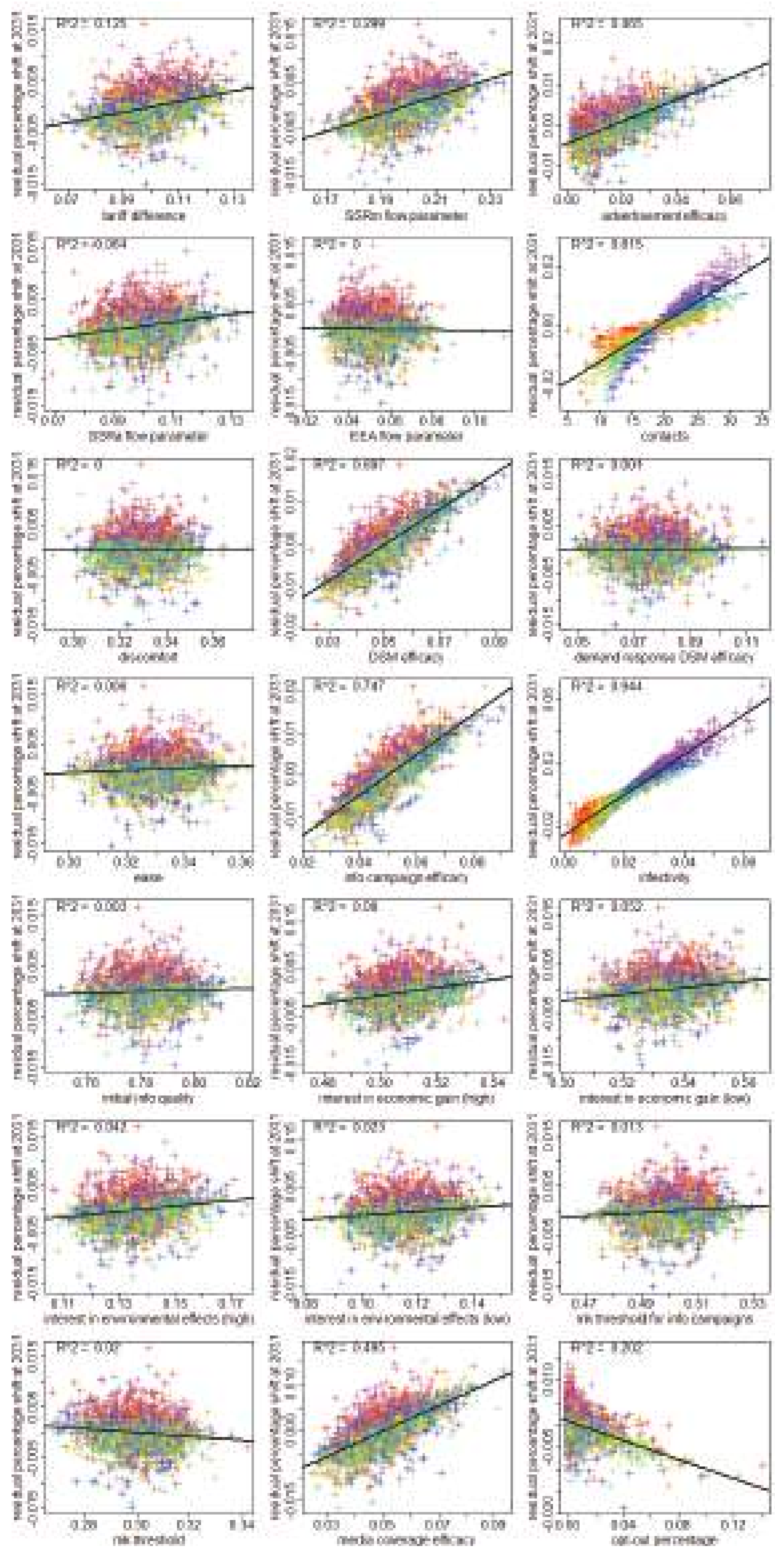

Figure 20: Scatter plot of Aggregate Consumption Shift vs. model parameters - multivariate regression

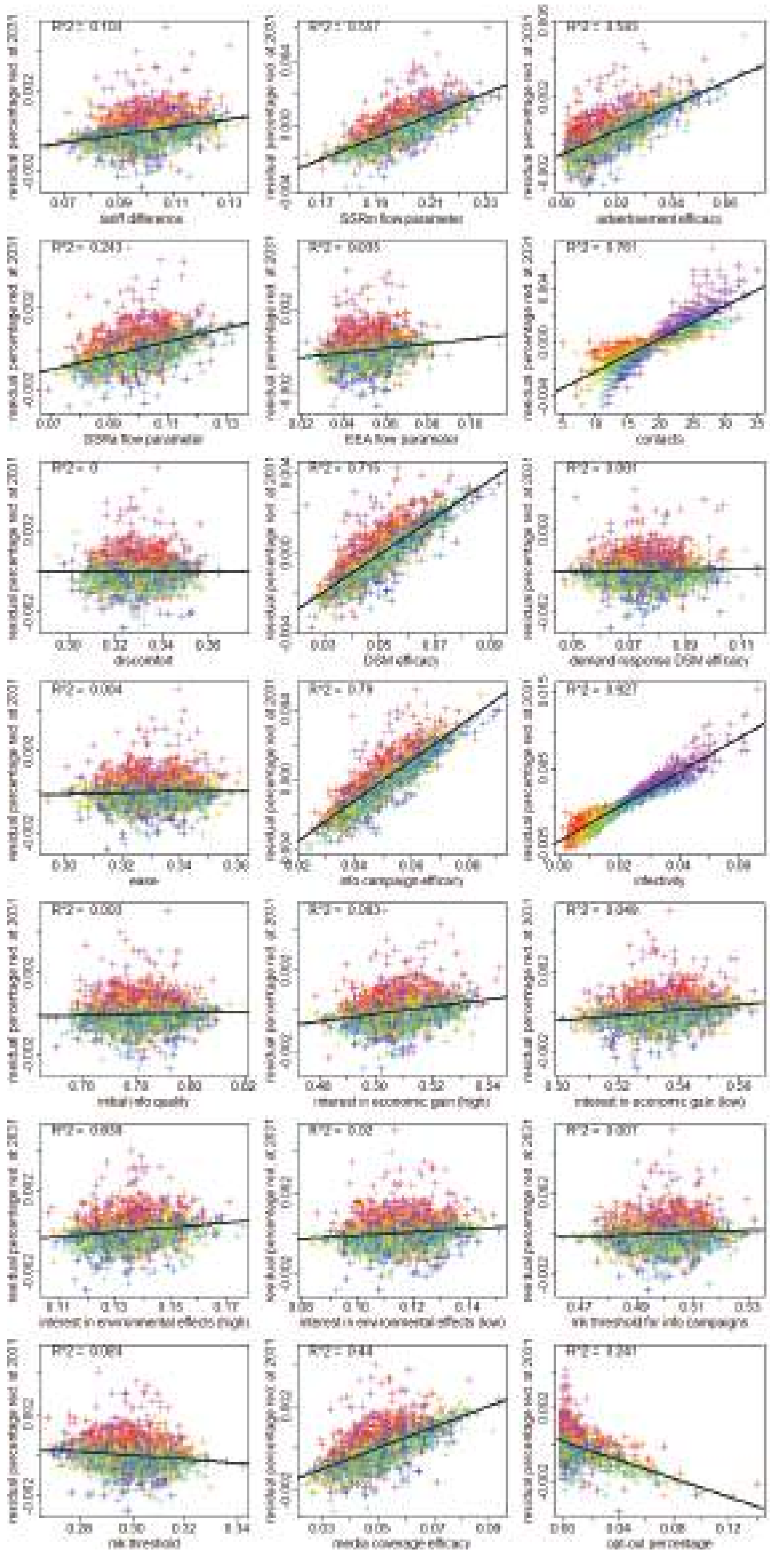

Figure 21: Scatter plot of Aggregate Consumption Reduction vs. model parameters - multivariate regression

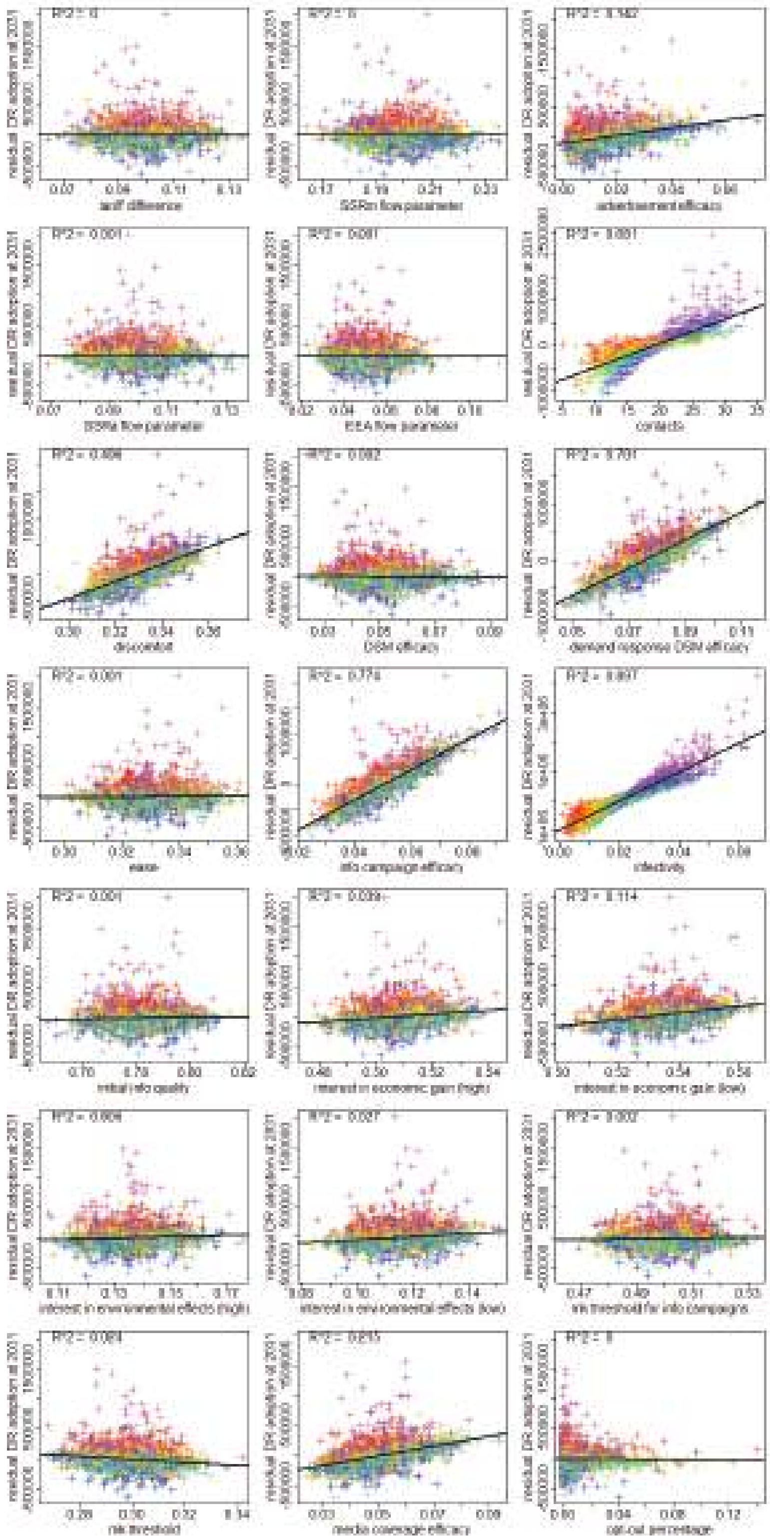

Figure 22: Scatter plot of Demand Response adoption vs. model parameters - multivariate regression

Model Parameter	β est.	β est. std. dev.	t-statistic	significance
infectivity	1.28E+00	5.97E-03	2.14E+02	***
contacts	1.36E-03	1.33E-05	1.02E+02	***
information-campaigns efficacy	4.85E-01	5.79E-03	8.38E+01	***
demand-side-management efficacy	4.26E-01	5.75E-03	7.42E+01	***
media-coverage efficacy	2.72E-01	5.68E-03	4.80E+01	***
advertisement efficacy	2.68E-01	5.88E-03	4.56E+01	***
SSRm flow parameter	1.88E-01	5.87E-03	3.20E+01	***
opt-out percentage	-1.07E-01	4.42E-03	-2.42E+01	***
tariff-difference	1.02E-01	5.71E-03	1.79E+01	***
interest in economic gain	8.34E-02	5.89E-03	1.42E+01	***
SSRa flow parameter	7.44E-02	6.03E-03	1.24E+01	***
interest in economic gain 0	6.85E-02	5.85E-03	1.17E+01	***
interest in environmental effects	5.80E-02	5.76E-03	1.01E+01	***
interest in environmental effects 0	4.33E-02	5.79E-03	7.48E+00	***
available market threshold value	-3.91E-02	5.73E-03	-6.82E+00	***
available market threshold value for information campaigns	3.32E-02	5.97E-03	5.57E+00	***
ease parameter	2.28E-02	5.94E-03	3.84E+00	***
initial-information quality	1.48E-02	5.87E-03	2.51E+00	*
demand-side-management efficacy for demand response	7.79E-03	5.90E-03	1.32E+00	
EEA flow parameter	-4.33E-03	5.88E-03	-7.36E-01	
discomfort parameter	4.18E-03	5.76E-03	7.26E-01	

Figure 23: Summary indexes of Aggregate Consumption Shift vs. model parameters - multivariate regression

Model Parameter	β est.	β est. std. dev.	t-statistic	significance
infectivity	2.27E-01	1.25E-03	1.81E+02	***
information-campaigns efficacy	1.15E-01	1.22E-03	9.47E+01	***
contacts	2.42E-04	2.79E-06	8.68E+01	***
demand-side-management efficacy	9.35E-02	1.21E-03	7.75E+01	***
SSRm flow parameter	6.76E-02	1.23E-03	5.49E+01	***
advertisement efficacy	6.45E-02	1.24E-03	5.22E+01	***
media-coverage efficacy	5.10E-02	1.19E-03	4.28E+01	***
SSRa flow parameter	3.44E-02	1.27E-03	2.72E+01	***
opt-out percentage	-2.52E-02	9.28E-04	-2.71E+01	***
tariff-difference	1.91E-02	1.20E-03	1.60E+01	***
interest in economic gain	1.80E-02	1.24E-03	1.45E+01	***
interest in economic gain 0	1.39E-02	1.23E-03	1.13E+01	***
interest in environmental effects	1.17E-02	1.21E-03	9.68E+00	***
EEA flow parameter	1.12E-02	1.23E-03	9.10E+00	***
available market threshold value	-9.04E-03	1.20E-03	-7.51E+00	***
interest in environmental effects 0	8.39E-03	1.22E-03	6.90E+00	***
available market threshold value for information campaigns	5.13E-03	1.25E-03	4.09E+00	***
ease parameter	3.95E-03	1.25E-03	3.17E+00	**
initial-information quality	3.16E-03	1.23E-03	2.56E+00	*
demand-side-management efficacy for demand response	1.79E-03	1.24E-03	1.45E+00	
discomfort parameter	7.08E-04	1.21E-03	6.35E-01	

Figure 24: Summary indexes of Aggregate Consumption Reduction vs. model parameters - multivariate regression

Model Parameter	β est.	β est. std. dev.	t-statistic	significance
infectivity	5.01E+07	3.36E+05	1.49E+02	***
information-campaigns efficacy	2.97E+07	3.26E+05	9.12E+01	***
demand-side-management efficacy for demand response	2.49E+07	3.32E+05	7.50E+01	***
contacts	5.35E+04	7.47E+02	7.16E+01	***
discomfort parameter	1.58E+07	3.25E+05	4.85E+01	***
media-coverage efficacy	8.15E+06	3.20E+05	2.55E+01	***
advertisement efficacy	6.68E+06	3.31E+05	2.02E+01	***
interest in economic gain 0	5.88E+06	3.29E+05	1.78E+01	***
interest in economic gain	3.23E+06	3.32E+05	9.73E+00	***
interest in environmental effects 0	2.69E+06	3.26E+05	8.25E+00	***
available market threshold value	-2.47E+06	3.23E+05	-7.65E+00	***
interest in environmental effects	1.27E+06	3.24E+05	3.90E+00	***
available market threshold value for information campaigns	6.65E+05	3.36E+05	1.98E+00	*
demand-side-management efficacy	-6.27E+05	3.24E+05	-1.94E+00	.
SSRa flow parameter	-6.07E+05	3.39E+05	-1.79E+00	.
initial-information quality	5.53E+05	3.30E+05	1.67E+00	.
EEA flow parameter	-4.03E+05	3.30E+05	-1.22E+00	
ease parameter	3.71E+05	3.34E+05	1.11E+00	
opt-out percentage	-2.39E+05	2.49E+05	-9.60E-01	
tariff-difference	-2.05E+05	3.21E+05	-6.38E-01	
SSRm flow parameter	-1.13E+05	3.30E+05	-3.42E-01	

Figure 25: Summary indexes of Demand Response adoption vs. model parameters - multivariate regression

Appendix E: Additional graphs

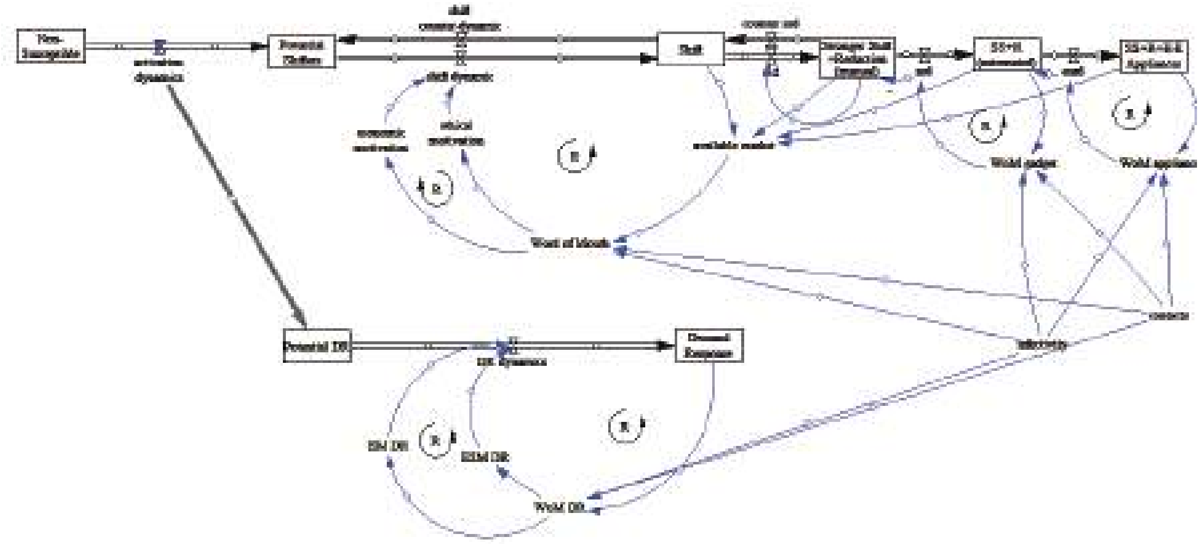

Figure 26: Word of Mouth feedback loop

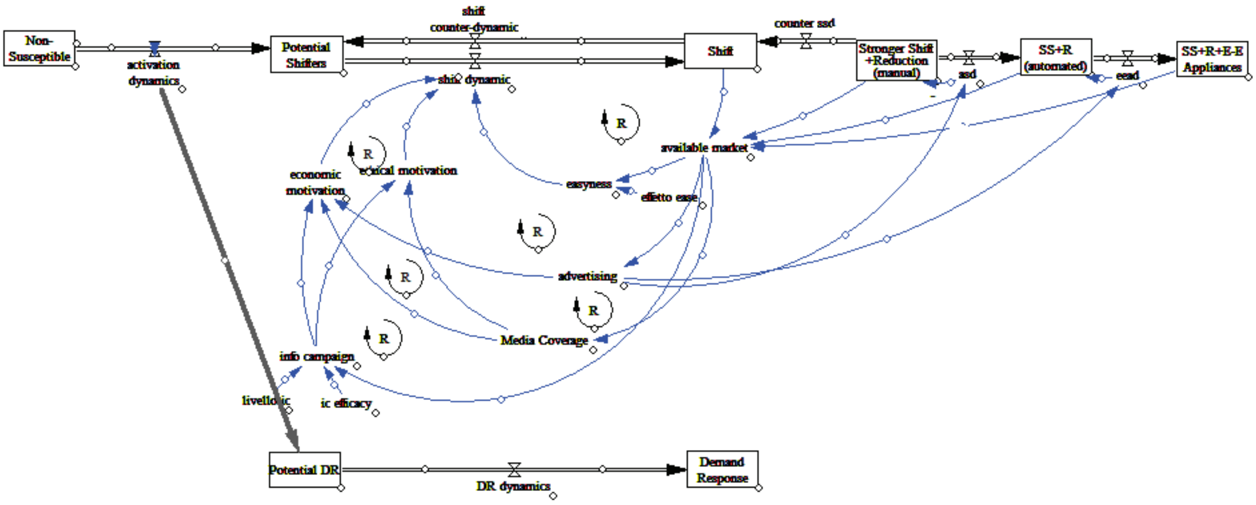

Figure 27: Available Market – Ease – Media Coverage - Advertising feedback loops

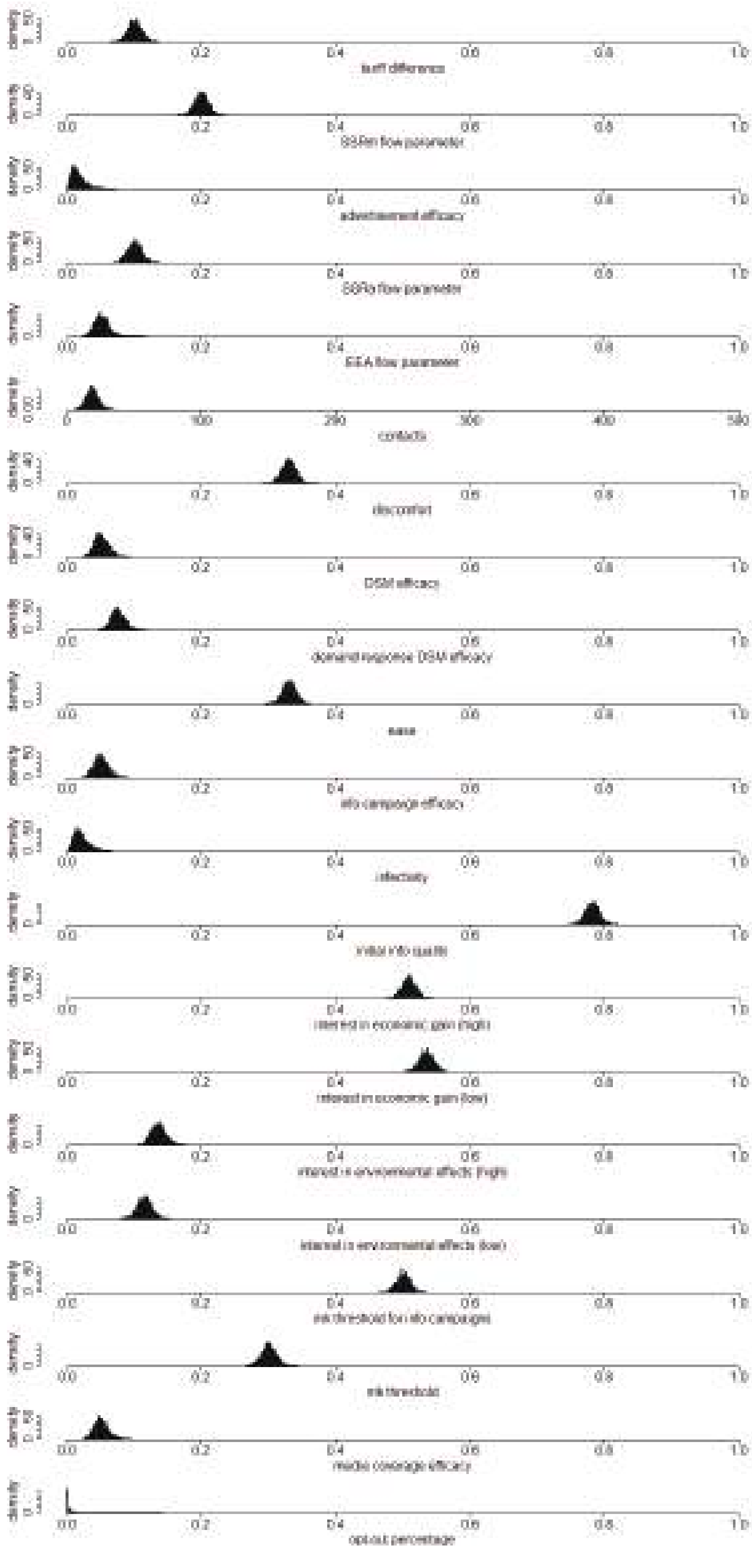

Figure 28: Parameter sample densities