Energy Savings in Common Areas of Buildings

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Abstract

A single utility, SIG[1], ("Services Industriels de Genève") supplies electricity to the canton of Geneva (Switzerland). Its market covers about 280,000 customers (households, private and public sector) and 2'866 GWh in 2014. In 2008, this utility launched a program named "Communs d'Immeuble" (i.e. communal area of collective buildings). This program, still in progress, aims at saving electricity in communal areas. This energy is mainly used for lighting (hall, corridors, stairs, cellars, garage…) and common equipments (fans, pumps, lifts, common laundry…). This paper evaluates the impact achieved by the "Communs d'Immeuble" program.

The initial aim of that program targeted 20 GWh/y of savings, which has been now exceeded. For each refurbished building an ex-ante appraisal was required. Hence, once we know the "real" savings, called "ex-post", we can evaluate the gap between ex-ante and ex-post assessments. Ex-post energy savings are difficult to appraise because measuring the unobservable (i.e. a non-existent consumption) is not a simple matter. The ways to do it are multiple and there is no clear-cut solution. The methodology hence is very rich: counterfactual analyses, bottom-up, top-down, parametric and non-parametric models... The aim of this contribution is to present some of these approaches to show that rich data-bases allow to design more completely and correctly the behaviours one tries to describe through statistical modelization.

After a brief description of the program (Introduction) and the data (section 2.1), the assessment methodologies are explained in section (2.2 and 2.3), followed by the results and conclusion (section 2.4).

1. Introduction: The efficiency program for Common Areas of Buildings

Before the program started, the electrical consumption of communal areas amounted about to 12% of the total consumption of electricity in the canton of Geneva and 32% of collective buildings. This large quantity of energy appeared to be an interesting potential for electricity savings because:

- The equipments are easy to access (outside of the flats and offices).
- The number of representatives with whom to negotiate is relatively small (one owners' representative per building).
- A change in the regulation in Geneva gave an excellent opportunity to obtain easy "negawatts"[2].

SIG took this opportunity to develop an incentive program for common areas. The first step (2009-2011) has focussed exclusively on lighting, since 2012 the refurbishment of the common laundries was launched. An initial two years' phase was devoted to:

- Evaluate the appliances that fulfil the expected specifications;

[1] This research was financially and technically supported by SIG who provided us with information from their customer data-base for the purpose of this project.

[2] Until 2004, only 12 hours per day or 24 hours lighting was mandatory in common halls and in staircases. Since 2005, one could take the opportunity of the new regulation to refurbish lighting by a system controlled by a presence detector, and more recently to introduce LED.

- Train the electricians about the new appliances;
- Convince the owners' representatives of the merits of the program.

The program consisted in an incentive corresponding to 10% of the annual bill in the beginning, then to 0.21 CHF[3], lowered to 0.05 CHF now, for each saved kWh/year; the kWh are not cumulated along the life expectancy of the new equipment, therefore the incentive corresponds to a one year savings.

Some pilot projects took place in 2008, and then the program has developed rapidly as illustrated in Table 1. The electricians were requested to estimate the savings produced by their interventions; they were trained to fill an online tool which estimates the savings. This estimation is called "ex-ante" savings in the following. So in 2015, the total ex-ante savings amounts to 23 GWh/y (even more because some buildings are missing, see note in Table 1).

The lighting of 2389 buildings and the common laundry of 479 buildings were renovated. Among them, 172 buildings have benefited from both sub-programs (rarely in the same year).

Table 1. Number of refurbishments by year (lighting, common laundry end ex-ante estimated savings in kWh/y)

	Number of buildings		Ex-ante savings (kWh/y)				
	Lighting	Common laundry	Mean lighting	Mean common laundry	Total lighting	Total common laundry	Total
2008	4		-5 299		-21’196		-21’196
2009	103		-7 295		-751’385		-751’385
2010	262		-6 465		-1’693’830		-1’693’830
2011	304		-7 186		-21’84’544		-2’184’544
2012	539	82	-8 825	-3393	-4’756’675	-278’226	-5’034’901
2013	581	142	-8 424	-3424	-4’894’344	-486’208	-5’380’552
2014	386	149	-9 530	-3907	-3’678’580	-582’143	-4’260’723
2015[4]	210	106	-14 405	-5927	-3’025’050	-628’262	-3’653’312
Total	2'389	479	-9 260	-4071	-21’005’604	-1’974’839	-22’980’443

An important question we address in this communication is to compare the ex-ante savings to the ex-post savings. In a previous paper (2012) we have discussed various ways to proceed. Here we shall mainly use the variation of electricity consumption calculated as the difference of two successive meter readings[5]. Clearly, this difference cannot be considered as the savings for an individual case, but, when the sample of observations increases, we may use the mean difference as an estimator of the mean savings for the sample of buildings. Let us illustrate this by supposing this simple model:

$$\Delta_{i,t} = \lambda_{i,t} + \epsilon_{i,t} \qquad (1)$$

Where

$\Delta_{i,t}$ is the observed variation on electricity consumption of building i between year t and $t-\tau$. The lag τ is generally larger than one[6]; $i = 1, \dots, N$, N is the sample size;

$\lambda_{i,t}$ is the effect of the refurbishment of building i in year t;

[3] 1 CHF ≈ 1.1 Euro.

[4] An accident in the computer program of the utility has stopped the registration of the data in June 2015. So the 2015 row includes only half of the year.

[5] In Geneva, the meters of small and medium consumers are registered once a year.

[6] We use generally a lag larger than one year for two reasons: 1) in order to properly measure the effect of the renovation, we must compare one full year with the old appliance and another full year with the new one, as the refurbishment takes place in an intermediate year, we have to take at least a two years gap 2) some refurbishments were made in several stages covering more than one year.

$\epsilon_{i,t}$ a random variable denoting the evolution of the electricity consumption of the building i other than the laundry or lighting.

We assume that the random variable $\epsilon_{i,t,}$ has zero expectancy and $E(\lambda_{i,t}\epsilon_{i,t}) = 0$. So the averaging of $\Delta_{i,t}$ for $i = 1, \ldots, N$ can be considered as an estimator of the mean effect of refurbishment, $E(\lambda_{i,t}) = \bar{\lambda}_t$. We expect $\bar{\lambda}_t$ to be negative. Note that this estimate measures the effect of the refurbishments of the buildings which benefited from incentives, it does not integrate the evolution of the non-participant buildings. To put it in other words: $\bar{\lambda}_t$ is an assessment of the renovation, it is not definitely an assessment of the program. We shall come back to this item in the next sections. In eq. (1) $\bar{\lambda}_t$ is a global measure mixing the effects of lighting and common laundry. In section 2.2, we propose an adaptation of eq. (1) to assess separately the mean effect of each appliance.

2. Data and descriptive results

2.1 Evolution of electricity consumption

Figure 1 shows the average electricity consumption of the communal areas by year (2007-2015). The left group is made of buildings which didn't participate. The central group is made of buildings that registered to the program: some have begun to renovate, others are still waiting or have renounced to go further, it is a mixed group difficult to analyse. The right set contains buildings which were refurbished and which received the incentive. The mean electricity consumption decreases steadily along time because all the renovated buildings are combined whatever the year when the work was ended; note that the columns in Figure 1 correspond to the date of the meter reading and not to the renovation date. From this figure we notice that:

- The effect of the program is certainly significant;
- Before refurbishment, the mean consumption of participants is larger than the one of non-participants;
- The intermediate group is heterogeneous, as already mentioned;
- Non-participants have reduced by 2860 kWh/y and participants by 9494 kWh/y in average from 2008 to 2015.

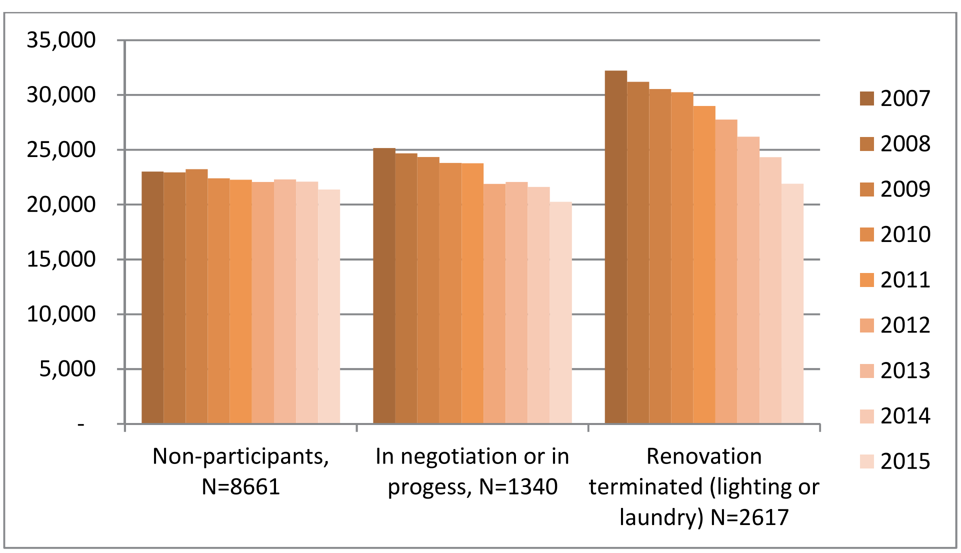

Figure 1. Annual mean consumption of communal area of three groups of buildings (kWh/y)

2.2 Ex-post estimation of savings: a first appraisal

Here we apply the estimator of eq. (1) and the ex-post savings are systematically calculated as the difference between consumption in 2015 minus consumption in 2008. We use this lag uniformly for the whole sample for three reasons: 1) for several buildings the refurbishment was made in successive steps and might has lasted several years, 2) as already mentioned, 172 buildings improved lighting and laundry, among them only 39 made both in the same year. This long lag introduces a bias because, in the same time, the equipment of some non-participant buildings was also renovated, certainly not at the same rate and not with the most performant technology. As, we see in Figure 1, the mean consumption of non-participants has lowered of 2860 kWh/y.

If this quantity corresponds to the natural evolution "out of program", should we correct our initial assessment by subtracting a quantity explaining this natural common evolution of both participants and non-participants? Should the savings be hence estimated by -9494 + 2860 = -6634 kWh/y[7]? A macro approach, including participants and non-participants, can help to answer this question and to better appraise the effect of the program (see next Section).

Table 2: Ex-post and mean ex-ante savings (kWh/y) according to eq. (1) estimated by differences in consumption between 2008 and 2015

	Ex-ante lighting & laundry	**Ex-post** lighting & laundry	
End of work	Mean estimated savings	Mean estimated savings	Total estimated savings
2008	-5'299	-6'264	-25'056
2009	-7'295	-6'077	-625'931
2010	-6'465	-8'797	-2'304'814
2011	-7'186	-8'626	-2'622'304
2012	-8'621	-11'422	-6'670'448
2013	-8'007	-9'148	-6'147'456
2014	-8'608	-8'848	-4'379'760
2015	-13'431	-10'238	-2'784'736
Total	**-8'524**	**-9'494**	**-25'560'505**

Note that the total column at the right of the table represents the estimated savings triggered by the program for the year of the operation. If we assume that savings are constant after the year of refurbishment, then total cumulated savings from 2008-2015, could be appraised as $-(1 \times 2'784'736 + 2 \times 4'379'760 + \cdots + 8 \times 25'056) = -89'976'049$ kWh. This first appraisal is still unsatisfying because it does not evaluate separately the impacts of laundry versus lighting, nor gives any insight of the counterfactual effect of the non-participants. We propose hereafter a linear model in order to separate lighting from laundry, and to incorporate the counterfactual effect (i.e. non-participants).

2.2 A global static model to evaluate savings

In the previous section, we have seen how the non-participant group interacts with the evaluation of savings. Here we propose this very simple model:

[7] 9694 kWh is the mean ex-post savings at the bottom of Table 2, 2860 kWh is the mean of the non-participants in Figure 1.

$\Delta_{i,t} = \alpha Ecl_i + \beta x_i + cons + \epsilon_{i,t}$ (2)

where

Ecl_i is a dummy variable equal to 1 if the lighting of building has been refurbished by the program, 0 otherwise;

x_i is the number of appliances replaced in the common laundry (between 0 and 8 in the sample);

So the parameter α is the mean savings for the renovation of lighting β is the mean savings due to the replacement of one appliance in the common laundry and $cons$, for constant, denotes the mean common evolution of the consumption of both participants and non-participants. We have estimated this model by Generalized least squares (White method) after exclusion of the central group ("In negotiation…") for which we lack information about renovation. The R-squared should not be directly interpreted because the weighting of observations increases it[8].

The estimated parameters are significant (cf. Table 3): the mean savings for lighting is -6134 kWh/y (less than Table 1) and the savings in the laundry is -1420 kWh/y per appliance. As an average of 2.75 appliances were replaced by laundry, the mean savings is estimated as 2.75× (-1420)= -3905 kWh/y by laundry, not far from the ex-ante calculation (Table 1). In conclusion, based on the static model, eq. (2), the estimated savings is lower than the level sketched in the descriptive approach (Table 1).

Table 3: Model (2) estimation

Source	SS	df	MS
Model	3.7987e+10	2	1.8993e+10
Residual	4.1102e+10	9720	4228561.79
Total	7.9088e+10	9722	8134977.11

Number of obs	= 9723
F(2, 9720)	= 4491.67
Prob > F	= 0.0000
R-squared	= 0.4803
Adj R-squared	= 0.4802
Root MSE	= 2056.3

Delta	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Ecl	-6134.476	67.57546	-90.78	0.000	-6266.938	-6002.015
x	-1419.765	59.15471	-24.00	0.000	-1535.721	-1303.81
_cons	-2440.165	22.22665	-109.79	0.000	-2483.734	-2396.596

One partial and possible explanation of this lower result compared to Table 1 or 2, especially for lighting, lies in the fact that some electricians developed this new activity without declaring their work to the program, because the incentive was judged insufficient, but the benefit for the electrician substantial. This is a good example of spill-over effect, meaning that some non-participant buildings have been refurbished thank to the program[9].

We think that a bottom up static model is sometimes insufficient to appraise simultaneously the rate of renovation of participants and non-participants but also to detect spill-over effect. Horowitz (2011) says:

"*Time series and pooled cross-section time series or "panel" econometric models are not only able to overcome the short-sightedness and narrowness of conventional program impact evaluations, but are also able to eliminate the need for supplemental studies that help transform program energy savings to net impacts from gross impacts*".

The same kind of arguments can be read in Parfomak & Lave (1996) or Fillipni and Hunt (2015). So we present such a top down model in the next section.

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[8] The R-squared on the original variables is 0.12.

[9] A survey of owners and electricians is underway in order to evaluate this phenomenon.

2.3 A dynamic top down model

To explain the variations in time of electricity aggregate demand for communal areas of buildings we propose a dynamic model based on four equations. This model was developed by Carlevaro & alii (1992), Carlevaro and Bertholet (1993). The first equation expresses the short-term demand in the form of the following identity:

$$q_t = u_t s_t \quad (3)$$

with

q_t electricity consumption in time *t*,
s_t equipment power in communal area in time *t*,
u_t the intensity of use of that power in *t*.

The following equation explains the intensity u_t through short term economical explanatory variables. We chose the following analytic form:

$$u_t = \exp\{\sum_{j=1}^{m} \alpha_j F_j(x_t^j)\}, \quad (4)$$

In which

x_t^j short-term variable in *t*,
F_j a known monotonic transformation of this variable,
α_j a parameter to estimate measuring the effect of x_t^j onto the intensity.

An adequate choice of this transformation guarantees positive u_t. By taking $F_j(x_t^j) = {}^1/_{x_t^t}$ and $\alpha_j > 0$, the u_t will lie between zero and one.

The two last equations express the evolution mechanism of s_t. The first one establishes a long term equilibrium state s_t^*. The other one describes the mechanism of the evolution of s_t according to the distance between that variable and s_t^*.

We define a long-term equipment stock as:

$$s_t^* = N_t^* c_t^* e_t^* \quad (5)$$

where

N_t^* the potential client population for the equipment,
c_t^* the equipment "potential" rate per eligible client, measured by the capacity of this stock to provide services;
e_t^* the specific consumption of the equipment, i.e. the electricity consumption of a new equipment for one unity of service.

We can interpret s_t^* as a potential market measured by its power. In the applications, the variables N_t^*, c_t^* and e_t^* are known or unknown. In the latter case, they are eliminated and explained by the way of long-term determinants. For the potential rate, c_t^*, these determinants express expectations on which investment decisions are based on the facilities of an eligible customer. The relation can take the following form:

$$s_t^* = \exp\{\beta_0 + \sum_{j=1}^{n} \beta_j G_j(z_t^j)\} \quad (6)$$

where

z_t^j a long-term factor valuated at time t,
G_j a monotonic transform of this factor,
β_j a parameter to estimate linking s_t^* to z_t^j.

If any variable factorizing s_t^* in (3) is known, for example N_t^*, it will be introduced directly in eq. (4), such that $\beta_j G_j(z_t^j) = \log N_t^*$.

The evolution of the stock of equipment available is described by the following recurrence equation:

$$\frac{s_t}{s_{t-1}} = \left(\frac{s_t^*}{s_{t-1}}\right)^k, 0 < k < 1. \quad (7)$$

This equation reflects a "partial adjustment" of s_t to s_t^*, at time t, according the "speed" k. This adjustment is even faster than k is large. At the limit, for $k=1$, the adjustment is "immediate". Conversely, for $k=0$, there is no adjustment and the stock of equipment available remains constant at its initial level. In the intermediate case, $0 < k < 1$, the adjustment operates over time, but with an efficiency that fades over time, cf. eq. (5), starting at initial time $t_0<t$:

$$s_t = \{\prod_{\tau=0}^{t-t_0-1}[s_{t-\tau}^*]^{k(1-k)^\tau}\}s_{t_0}^{(1-k)^{t-t_0}} \tag{8}$$

The convergence of the equipment towards its "potential stock" is only possible in a steady state, that is if $s_t^* = s^*$, t=1,2,... . The solution of eq. (6) is then:

$$s_t = s^* \left(\frac{s_{t_0}}{s^*}\right)^{(1-k)^{t-t_0}} . \tag{9}$$

This solution gives the path for s_t in time converging to s*, as $t \to \infty$. In reality, when the external conditions change, the stock level s_t is continuously deviated. We outline two interpretations of that mechanism of partial adjustment:

1. The first interpretation is microeconomic. It identifies the long-term ratio of equipment to a level of equipment "desired" by the representative individual of the potential population, that is to say a level of equipment which the individual seeks to develop. The partial adjustment mechanism then reflects the difficulties (technological, financial, psychological, institutional, etc.) encountered by this individual to fill the gap felt between the equipment he has and that he would like.
2. The second interpretation is macroeconomic. It responds to criticism of the microeconomic interpretation when such equipment is represented by a unique equipment or installation (a heating system, for example). Indeed, for this type of equipment, the growth of stock available in the potential population develops through the dissemination of that good for consumers who do not yet possess and not by the increase of a hypothetical average stock owned by each individual of the potential population. In such cases, the partial adjustment mechanism would express the information propagation process on the equipment in a population where potential buyers are still unsure as to the relevance of this equipment for their own operations. In other words, he would describe the "demonstration effect" exerted by the owners of such equipment on those who, while being likely to have, do not yet have them.

This model is an attempt to develop a technical-econometric explanation of demand for electricity, it is important to stress, at this stage, the main application limits of such an instrument. In particular, two major mechanisms that determine the demand for electricity in reality are not described explicitly in this model. The above model is poor for the replacement of the existing equipment when one has to distinguish among diffusion and replacement. In our situation, as each building is definitely equipped as soon it is finished, the model appraises only the replacement of appliances.

In order to simplify the estimation process, we transform the eq. (3) by taking the following pseudo first difference: $\log(q_t) - (1-k)\log(q_{t-1})$, which leads to: (10)

$$\log q_t = \beta_0 k + \sum_{j=1}^{m} \alpha_j\left[F_j(x_t^j) - (1-k)F_j(x_{t-1}^j)\right] + \sum_{j=1}^{n} \beta_j k G_j(z_t^j) \quad + (1-k)\log q_{t-1}$$

Adaptation of the model to the communal area program

In order to evaluate the effect of the program, we propose to make the adaptation speed dependent on the program, more precisely on the incentives. So we change the definition of k as:

$$k_t = \frac{k}{1+\frac{1}{\exp(\theta D_{t-1})}} \tag{11}$$

Where D_t is the total amount of incentives given in year *t*. We notice that the incentives are lagged in order to leave enough time between renovation and its impact on the meter reading. When the incentive is zero (before 2008) $k_t = \frac{1}{2}k$. As the level of incentive increases k_t approaches k (inasmuch θ is positive, what is expected by hypothesis). In order to detect the effect of the program, we compare the estimated values of consumption by keeping incentive equal to zero with the same estimated values using now the observed D_t. Furthermore, we can suppress exogenous random effect by replacing the lagged $q_{t-1}$by its own estimated by the model since 2010. So we compare net values, with and without incentive.

2.4 Results and conclusions

We have estimated the model (3) transformed in eq. (10) using the followings variables:

q_t aggregated electricity consumption in year *t* for the communal areas;

N_t^* number of apartments in multi-family buildings, = $\exp(\beta_1 G_1(z_t^1))$ as stated in the comment of eq. (6);

e_t^* specific consumption of lighting and laundry[10] , = $\exp(\beta_2 G_2(z_t^2))$;

c_t^* is calculated through eq. (6), but was considered as constant ($\beta_j = 0, j > 0$).

u_t for u_t , the short term intensity of use cf. eq. (4), we use only one explanatory variable (heating-degrees: *HD*t), then $u_t = \alpha_1 {}^1/_{HD_t}$. This variable is an indicator of the temperature of the cold water distributed in the buildings: Zraggen (2010) measured the water's temperature in 2006/2007, the difference between the lowest and highest temperature was about 8 degrees. The impact of that difference is more significant when one uses low temperature washings more systematically.

k is transformed as exp(K), so k>0.

The estimated "speed" of diffusion introduced in eq. (11) is presented in Figure 3, its value changes from 0.07 before the program to 0.13 (+97%), indicating a positive effect of the program on the renovation rate. The observed and estimated annual electricity consumption is given in Figure 2.

Table 4: Model (10) estimation

Source	SS	df	MS		
Model	3867.04607	4	966.761518	Number of obs =	24
Residual	.004581676	20	.000229084	R-squared =	1.0000
				Adj R-squared =	1.0000
				Root MSE =	.0151355
Total	3867.05065	24	161.12711	Res. dev. =	-137.4208

ly	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
/alpha0	7.733118	.0530328	145.82	0.000	7.622494	7.843743
/K	-2.001612	.238459	-8.39	0.000	-2.499029	-1.504195
/theta	.0057628	.0203516	0.28	0.780	-.0366898	.0482154
/alpha1	47.2543	98.29188	0.48	0.636	-157.779	252.2876

The comparison of the estimated values with and without incentive is presented in the Figure 4. Let's recall that the forecasted values use the lagged value of annual consumption estimated by the model since 2010.

[10] This quantity was computed by gathering technical information from different sources: official statistics (OCSAT, Geneva, OFS Switzerland), information from the Swiss Energy Agency and the European Commission.

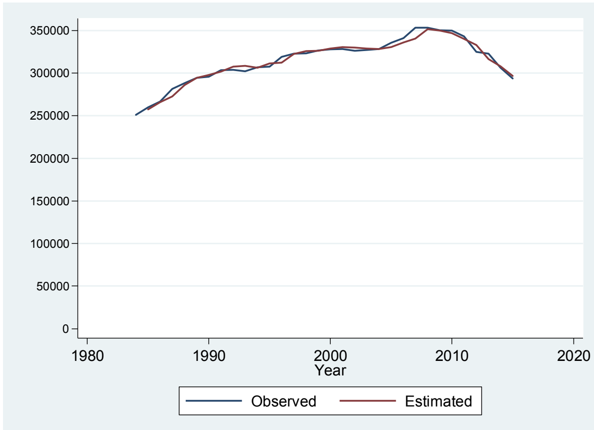

Figure 2. Annual consumption for communal areas in Geneva: observed and estimated values (MWh)

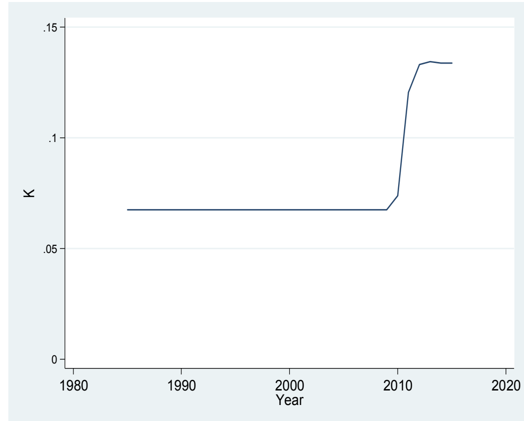

Figure 3. Evolutions of the *k* parameter (speed of diffusion)

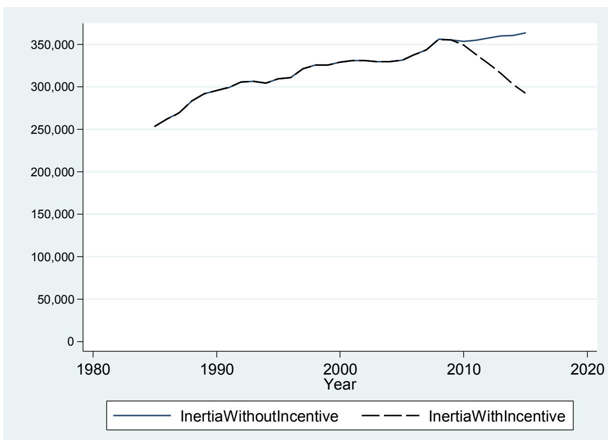

Figure 4. Annual estimated consumption with and without incentives of the program (MWh)

The cumulative sum of the annual differences between the two estimated series amounts to -223'610 MWh for the period 2010-2015. So, the estimated savings calculated by the dynamic model is much larger than our previous appraisal proposed at the end of Section 2.1 (-89'976 MWh). This last quantity includes the effects we missed in the above trials: renovations not registered in the data base since last summer and spill-over effects, but also other programs and regulation. The dynamic approach is more valuable because it treats simultaneously participants and non-participants, moreover it includes the incentives in order to assess the impact of the program, and finally the dynamic specification introduces the inertia of the system which is so often underestimated by program managers. The true savings generated by the program are probably lower than the above 224 GWh. We are now doing a survey on the electricians and owners in order to precisely assess spill-over. So we shall improve our quantitative assessment of indirect effects.

Conclusions: Firstly, when comparing ex-ante savings with the difference in consumptions defined in eq. (1), we observe the high consistency between ex-post and ex-ante assessment. Secondly, we succeeded in evaluating separately the savings from lighting and laundry, which can help in the optimal managing of the program. Thirdly, the long existence of this program –more than eight years– induces a particular issue pertaining the situation of the non-participants. The market in Geneva is relatively small (about 20'000 multi-family buildings) and the electricians have certainly worked for both groups, hence we have suspected some spill-over effects. We have partially answered this issue thanks to the dynamic model. We can attribute certainly the decrease of the total consumption to the undertaken work, but to which extent can we equally attribute it to the program? During the eight years of the program, non-participants have been refurbished at their "natural" rate, and maybe with less efficient appliances than for the participants. Should we subtract the decrease of the non-participants from that of the participants as if there were a bias selection (cf. section 2.2)? We think that the response refers to the role of efficiency programs: efficiency programs aim at accelerating the diffusion of new technologies. Hence, sooner or later, the non-participant group will catch up with the participants. The shorter is the term, the more successful is the program.

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