Modelling Energy Efficiency in Residential Buildings with Closed Housing Markets: A Static CGE Approach

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Abstract

This paper aims at modelling an energy efficiency policy in order to evaluate its consequences on real estate and energy consumption. We use the closed general equilibrium model IMACLIM-S, that represents France's economy in 2004. After having introduce the households and firms maximization program, we define the rate of occupied buildings, that closes the supply and demand equilibrium. This rate is the key to understand the mechanism. The money amount invested in energy efficiency is not allocated to construction and therefore the pressure on estate increases, as for the rate of occupied buildings. This higher rate is responsible for a higher rent, due to the decrease of vacant buildings. There is no distinction between home-owners and renters in this model, only one aggregated household. This higher rent will be responsible for inflation.

We are in a perfect asymetric information situation, where households do not know they could extract a higher rent from the fact their building is green. They only know they will use less energy to have the same life standard. It will be one of the several features that will be included within a next version of the paper. Here we observe the mechanism that says that "one euro invested in energy efficiency is one euro not invested in construction".

Contents

Introduction

Nowadays the demand for green buildings, with high energy and environmental standards, is exploding. The anticipation for a strong increase of energy prices is also responsible for a wilingness from both the governement and households to start renovation programs that aim at enhance buildings energy efficiency and consume less energy. All these programs do have a cost, and the investment in this field is not allocated to other sectors. We know that the whole households investment amount is devoted to construction. If this investment is reallocated to renovation, what will be the impact on buildings construction?

This first draft is written with the hypothesis that people do not have information about the rent they could have from the fact their home has high energy standards. We only observe the direct effect, that is the weaker demand for construction. The current trend around green estate marketing is absent from that model, it requires several big changes.

Methodology

IMACLIM-S, a "hybrid" model of a second best world

General description

IMACLIM-S is a hybrid general equilibrium model of the France economy. It is based on comparative statics. The economy, at a given time, undergoes an exogen deformation. For instance, this program has been the source to study the effects of the introduction of a carbon tax in France [3]. The adaptation to this deformation results from several elasticities. There is no way to know how is the economy during the transition.

The model is split into four sectors. Two are related to housing. They're represented and they're balanced in both money metric values and physical quantities (m^2). The building and home construction is a sector, that also includes renovation and property development. The other one can be called "Housing Services". This is the renting activity and the home-owning sector, that includes the imputed rents. In other words, one sector represents the creation of the housing "good", the other one is linked to the use of that sector.
One of these sectors are linked to housing energy services, which is explicitly represented in both money metric values and physical quantities (MTep). This sector represents the use of energy intended for housing : heat, cook. etc... The last sector is called "Composite good", this the whole rest of the economy.

Labour market representation

In our model, producers operate in static equilibrium with a fixed input of labour per unit of output, this is labour productivity. The advantage of IMACLIM-S is a possibility to model the under-utilisation of labour as a production factor, the unemployment. There is a rigidity of real wages represented by a wage curve. They are adjusted instantaneously to the economy in the static equilibrium, but not in an optimal way. There is an elasticity between wage and unemployment.

The housing market model

Household behavior

This demand results from a utility maximization program. The household utility function take into account the consumption of housing services $H(m^2)$, consumption of non-housing and non-energy goods and services C, and consumption linked to the housing energy services S_h.

S_h is an energy service, and do not directly reprensent the energy consumption. This service needs a certain energy amount to be reached. This is for instance the temperature required to live in the home. $S_{h_{bn}}$ is linked with C_{E_h}, the housing energy products consumption, by the relation $S_h = \kappa C_{E_h}$, where κ is the energy efficiency. The function is:

$$U(C, H, S_h) = (H - H_{bn})^{\alpha'} \left((C - C_{bn})^{\epsilon_C} (S_h - S_{h_{bn}})^{\epsilon_S}\right)^{\alpha} \tag{1}$$

where H_{bn} is the basic need for housing services, $S_{h_{bn}}$ for energy products linked to housing and C_{bn} the basic need for composite good. This is a particularity of our model, based on an obvious fact of the daily life. People often need things with a minimal quantity to live. For instance, a minimal housing surface is an imperative to live decently, without taking into account preferences for living space. People also need to have a minimal housing temperature to live, that is the reason for $S_{h_{bn}}$. The form of this function is inspired from [5]

We chose this form of utility function in order to pull apart the housing services expenditures and the rest of the consumption. We have an arbitrage between composite goods and energy services for housing.

This utility function is maximized under a budget constraint shown below.

$$(1 - s)Y = P_C C + P_H H + P_{E_h} C_{E_h} \tag{2}$$

Y is the net total income (including imputed rents) and s the saving rate. Therefore we have the demand in each of these goods.

$$H - H_{bn} = \frac{\alpha'(C - C_{bn})}{\alpha \epsilon^C} \frac{P_C}{P_H} \tag{3}$$

$$C_{E_h} - C_{E_{h,bn}} = \frac{1}{\kappa} \frac{\epsilon^S (C - C_{bn})}{\epsilon^C} \frac{P_C}{P_{E_h}} \tag{4}$$

Firm behavior

All the firms have a CES production function:

$$Y_i = \left(\lambda_{li} L_i^{(\sigma_i - 1)/\sigma_i} + \lambda_{ki} K_i^{(\sigma_i - 1)/\sigma_i} + \sum_j \lambda_{ij} C_{ij}^{(\sigma_i - 1)/\sigma_i} \right)^{\sigma_i/(\sigma_i - 1)} \tag{5}$$

where L_i is the labor demand for firm i, K_i the need in capital and C_{ij} in intermediate good j. Intermediate goods are composite, housing energy products, housing services and construction because of auto-consumption. We also have constraints on these firms. This is one of the particularity of IMACLIM-S, there is a bottom unit consumption of capital, labor and intermediate goods [2]. This technical rigidity can be seen as:

$$k_i \geq \beta_{Ki} k_{i0} \tag{6}$$

$$l_i \geq \beta_{Li} l_{i0} \tag{7}$$

$$\forall j \quad CI_{ji} \geq \beta_{CI_{ji}} CI_{ji0} \tag{8}$$

where $\beta_{Ki}, \beta_{Li}, \beta_{CI_{ji}}$ are the technical asymptots of capital, labor and intermediate goods intensity.

We write the cost minimization program for these firms, and we obtain the consumption per unit of intermediate goods, labor and capital.

$$X_i = \frac{\Theta_i}{\Phi_i} \left[\beta_{X_i} X_{i0} + \left(\frac{\lambda_{X_i}}{P_X} \right)^{\sigma_i} \left(\lambda_{l_i}^{\sigma_i} P_l^{1-\sigma_i} + \lambda_{k_i}^{\sigma_i} P_k^{1-\sigma_i} + \sum_j \lambda_{C_{ji}}^{\sigma_i} P_{C_j}^{1-\sigma_i} \right)^{-\frac{1}{\rho}} \right] \tag{9}$$

with $X = (k, l, C_j)$. C_j is the unit consumption of intermediate goods, k the unit capital consumption and l the unit labor consumption. P_k is the price of machine capital, an average of the investement price of needed goods. Two characteristics are introduced here that modify the basic solution for the CES production function.

Θ_i reprensents static decreasing productivity, given by the equation:

$$\Theta_i = \left(\frac{Y_i}{Y_{i0}} \right)^{\sigma_{\Theta Y_i}} \tag{10}$$

$$\sigma_{\Theta Y_i} = \frac{\overline{\pi^i}}{1 - \overline{\pi^i}}$$

Φ_i represents the endogenous technical progress, neutral in Hicks's sense. In our model, Φ_i plays a role only for composite and building sector, not for the others. This is elastic to the variation of capital consumption, which is here taken equal to the cumulated investment.

$$\Phi_i = \left(\frac{k_i Y_i}{k_{i0} Y_{i0}} \right)^{\sigma_{\Phi_i}} \tag{11}$$

The resulting price of that model, for the building sector, is given by the equation shown below.

$$P_M M = P_k K + P_l L + \sum_{j=1}^{n} P_{C_j} C_j + \overline{\pi^M} \tag{12}$$

where $\overline{\pi^M}$ is the exogen surplus of the sector.

The housing services sector

We isolate this sector because of its special structure. Indeed, this is a sector which has only one output, capital. Therefore there is no substitution between labor or intermediate goods. The following parapraph details the structure. This sector has for input the building sector output. We can define the output price as the price of the quantity of housing consumed per year added to a mark-up (σ).

$$P_H = P_M \delta_H (1 + \sigma) \tag{13}$$

where δ_H represents the part of housing capital that is consumed every year. This output price correponds to the price of the rent of one meter square per year.

Equilibrium condition

We introduce τ, the rate of occupied buildings, which is defined by the relation $\tau = \frac{H}{A_b}$. A_b is the housing stock, the total quantity of housing surface on the land. This rate results from a difference between the supply and the demand due to a housing service price P_H higher than the market equilibrium price. There is a clear relation between the mark-up and this rate:

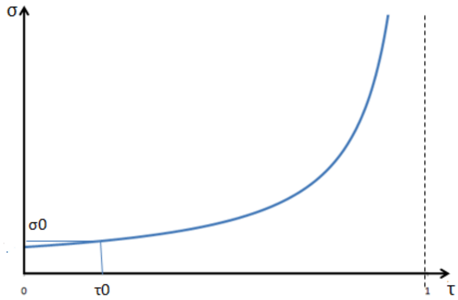
$$\sigma = f(\tau) \tag{14}$$

Since we need to put that variable in our model, we take for the function f the following form:

$$\forall\ 0 \leq \tau \leq 1 \quad f(\tau) = \tau^0 + \frac{\Omega \tau}{1 - \tau} \tag{15}$$

where σ^0 is the mark-up that corresponds to the reference situation and Ω is a sensitivity parameter. We introduce this parameter because we do not

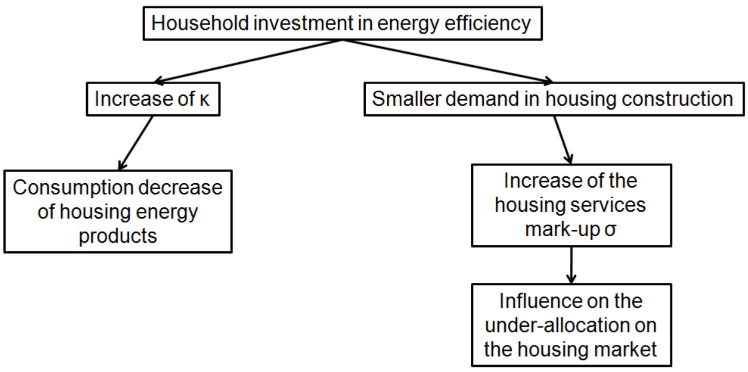
know the link strength between σ and τ. It will be a study parameter.
In this version of the paper, σ does not depend from κ because we assume there is no information about the rent linked to energy efficiency. To broke this hypothesis needs the introduction of the owner's knowledge about their green estate price.



Integration of energy efficiency

We state in this model that there is only one type of building. There is no distinction between normal and high environmental efficiency buildings. The resulting energy efficiency coefficient κ is an average of the environmental performance of each buildings. However this is still possible to come to a model with two types of building, by a process based on generations.

The effects we want to model are represented on the diagram shown below. The starting point is the household investment. We consider that this is the basis for an increase of energy efficiency. Two consequences follow from that investment. There is a reduction of housing energy consumption, and a weaker demand for construction. This weaker demand is linked with an increase of the mark-up, because the demand for housing services is not decreasing, and an under-allocation of housing surface.



Investment behavior

We divide the household investment in both housing investment, and energy efficiency investment. Each household makes a choice between buying housing surface or enhance the environmental performance of this surface. In the first case, the total housing stock is increasing. In the second case, there is a smaller total housing stock that uses less energy to produce the same energy service. The total household investment is given by:

$$I = iY \tag{16}$$

where Y is the total net income and i the investment rate. With our model we write:

$$I = (i_H + i_{EE})Y = I_H + I_{EE} \tag{17}$$

where i_H is the fraction allocated to housing and i_{EE} to energy efficiency. This investment results in an enhance of the energy efficiency coefficient κ. We write the relation:

$$\kappa = h(I_{EE}) \tag{18}$$

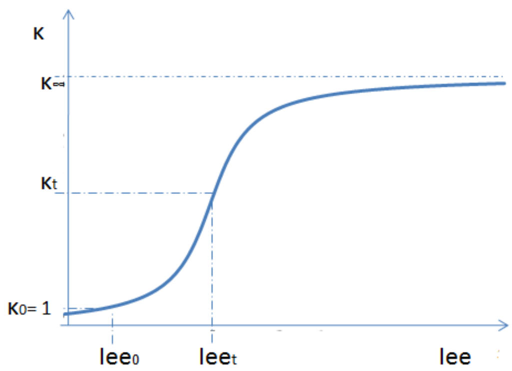
h of course is an increasing function. This function has a thresold because energy efficiency is not linear with the investment. To create a quantitative increase in κ calls for a high amount of money. For our model, we write the function

$$\kappa(I_{EE}) = \kappa_t + \frac{2}{\pi}(\kappa_\infty - \kappa_t)arctan\left(tan\left(\frac{\pi}{2}\frac{\kappa_0 - \kappa_t}{\kappa_\infty - \kappa_t}\right)\frac{I_{EE} - I_{EEt}}{I_{EEt} - I_{EE0}}\right) \tag{19}$$

κ_0 is the initial level of energy efficiency, κ_∞ represents a technical asymptot, due to the fact there is a strong inertia on buildings. Indeed, the major part of the energy efficiency improvment comes through the construction of new green buildings. But these buildings represent each year not more than 3% of the total estate. Therefore the renovation of the whole french estate will be a scenario on the very long time. This is the source of inertia.

The first part of this graph, where $\frac{\partial^2\kappa}{\partial^2 I_{EE}}$, for $I_{EE} < I_{EEt}$, is characterized by what we can call "*Learning by doing*", a crucial step of our mechanism where we observe an endogen growth. The energy efficiency market is far from being mature [1], and this is not a doubtful hypothesis to model its evolution like that.

We are here on the edge of the engineer's knowledge on energy efficiency technical process and the economist's know-how to translate that into a formal model.



Numerical results

Calibration and datas

This is probably the most important and difficult part of this paper. We are still within the birth of the energy efficiency market and datas are either insufficient or inadequate. It will be an interesting point to study for a later version of the paper.

Household utility function

The parameters of the equation [1] correpond to the budget part of each sector. According to the french national institute of statistics and economics studies (INSEE), 3% of the budget in 2004 is devoted to energy products and 18% to housing services [4]. Therefore we take:

α'	0.18
α	1
ϵ_C	0.79
ϵ_S	0.03

Basic needs are more difficult to evaluate. INSEE publishes each year some basic expenditures in several sectors. We only have the value for the composite good, that corresponds to food and transport expenditures. 30% of the composite good is seen as a basic need. In this model, we did not put values for housing services and energy products, for want of datas.

Investment function

We only know the reference parameters for 2004. According to ADEME, the investment level for household was about 10 GE. We take $\kappa_0 = 1$ for this value. The others values are strong hypothesis that need to be confirmed by datas.

κ_0	1
κ_∞	3
κ_t	2
I_{EEt} (M)	30

Building stock

The initial rate of unoccupied buildings is equal to 7% in our model, according to a study from INSEE [6].

French economy

The french economy values come from INSEE datas, that are published each year within "Les comptes de la nation". We need two tables. The first one is the TES, the input-output table that reprensents the France's cash-flow statement. There is also the TEE, a table that represents how the value-added is shared out between the different economic agents (governement, firms, households and the rest of the world).

Mark-up and rate of occupied buildings

We do not have data concerning a link between these two values. We decide to calibrate our model with $\Omega = 0.01$ (cf [15]), a value that gives us realistic and reasonable results.

Scenarii

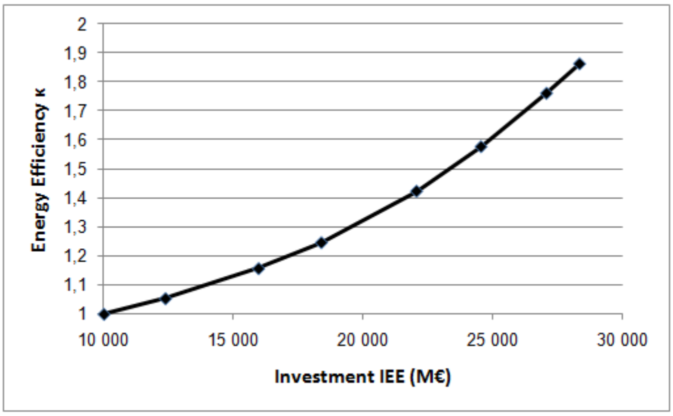
In this papier, we only study the variation effect of total investment in energy efficiency. The input is the variable i_{EE}, the part of investment devoted to energy efficiency. We realized several simulations with different values for this input.

The reference situation corresponds to an investment equal to $10Ge$, with $\kappa = 1$. The other points belongs to a situation where 20 years before 2004, a certain amount of investment (I_{EE}) has been devoted each year to energy efficiency.

Results

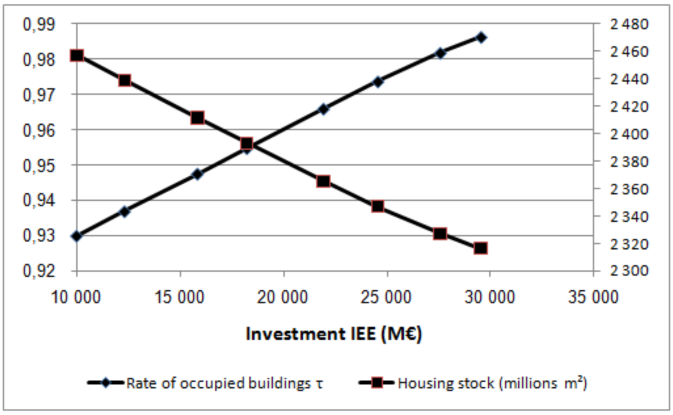
Effect on the energy efficiency

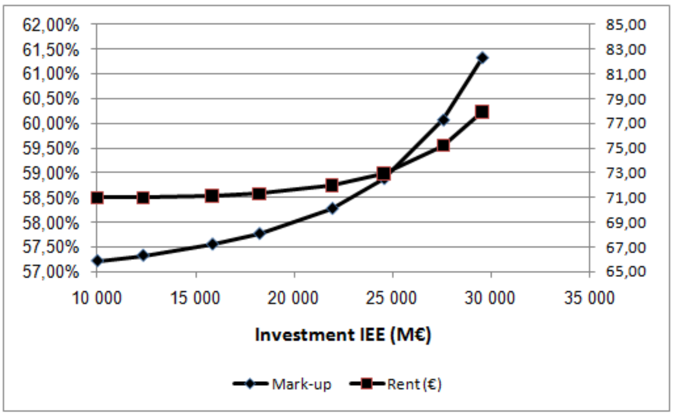
The graph shown below is the relation between the energy efficiency coefficient κ and the investment. We observe of course the first part of the graph described in a previous paragraph, with the "learning-by-doing" effect.



Effect on estate prices

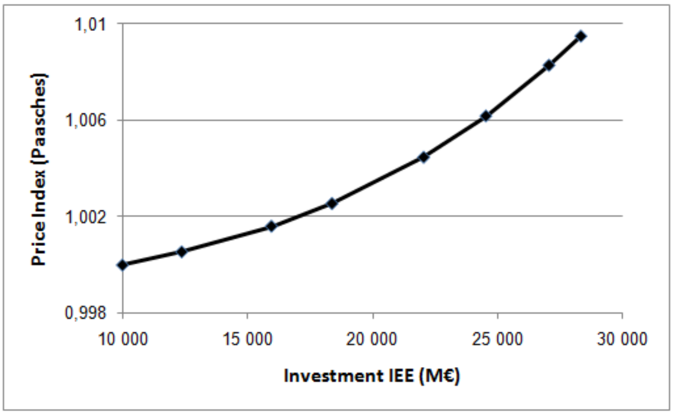
The results are not surprising. Because of the weaker demand for construction, there is each year a smaller stock than for the 2004 "real" situation. The rate of occupied buildings and the rent (the rental price for a meter square) are of course increasing.





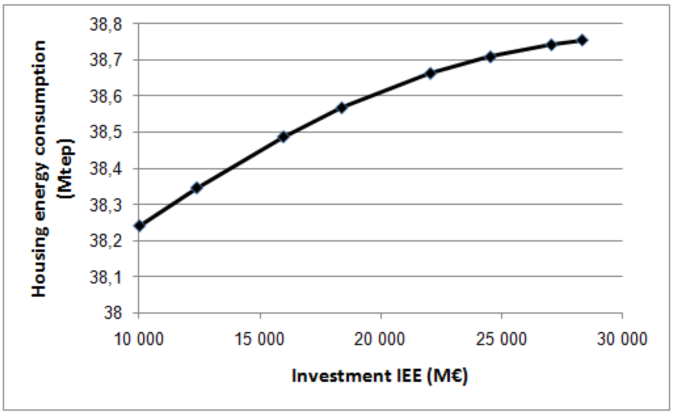
Effect on the economy

Here are the most surprising results of the study. Indeed, we observe a strong GDP increase. This is only due to the mark-up increase that generates inflation. Indeed, in our model, home-owners and renters are aggregated, they represent one single household, therefore there is no way to see how renters lose and how home-owners win from that situation. But the result is that globally the increase of the estate mark-up is responsible for a surplus. The graph that represented the GDP or the net total income are exactly derived from the following graph:



Effect on the housing energy consumption

At a first glance, a decrease of energy consumption is foreseeable, due to the new high energy standards of buildings. The result of our model shows an increase, as a consequence of a higher net total income. We reach here a limit of our model. The utility function described in the beginning of that paper is the simpliest form we can write, and there is a need for a better understanding of household behavior with the energy consumption.



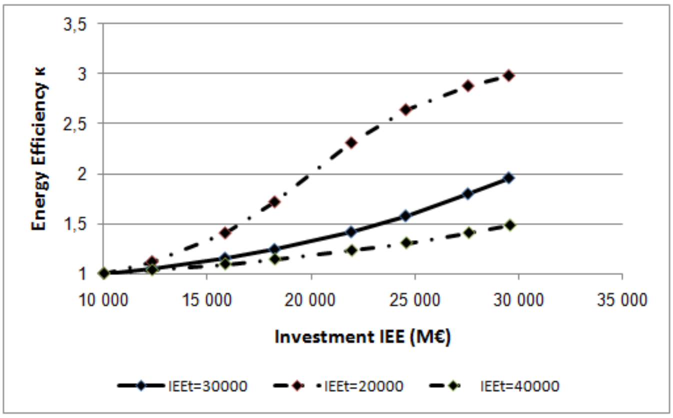
Parameters sensivity

Some hypothesis that have been made in the previous part are quite strong because there is no way to have datas. The energy efficiency market in France is one of the most developped in the world and is yet at its starting point. What about the investment required to reach the thresold? What about the technical asymptot κ_∞? All these questions can find an answer through a study of sensitivity on the most uncertain parameters.

Sensivity of the investment function

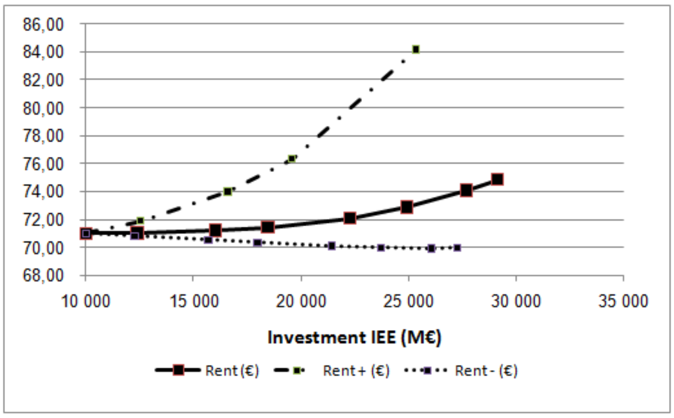
We study here the changes induced by a variation of I_{EEt} and κ_∞. In our model, there is no big dependancy to these parameters, except for the energy efficiency average level. Indeed, what we model is an ivestment shifting from construction to energy efficiency. But κ does not have an influence on the mark-up and therefore on renting price.

The only dependancy is the κ one and this is reprensented on the graph shown below, for several values of the investment thresold I_{EEt}.

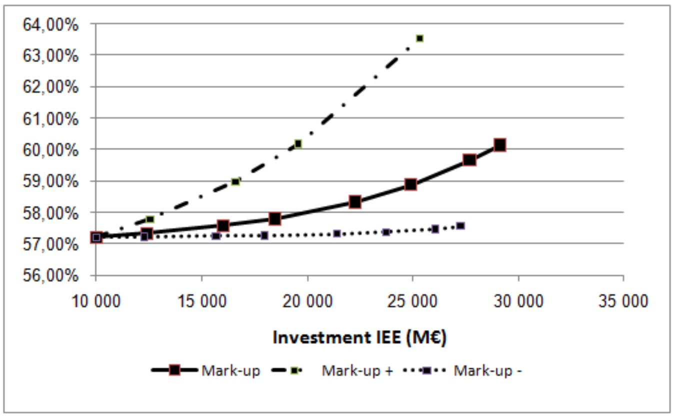


Sensivity of the mark-up parameter Ω

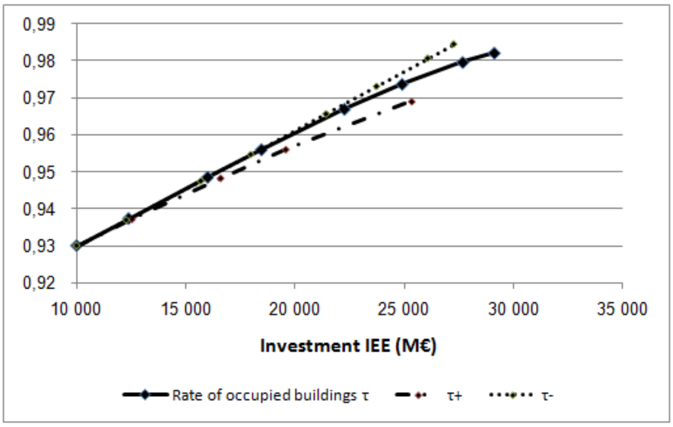
Ω is the constant introduced in the equation [15]. Due to the lack of datas on this function, this analysis is crucial. We realize two others groups of simulation. The first one with $\Omega = 0.05 > \Omega_{ref} = 0.01$, and the second one with $\Omega = 0.001$. There is no change on the energy efficiency level, because it only depends of the investment. However, there are big differences concerning the rent and the mark-up. If the mark-up varies strongly with τ ($\Omega = 0.05$), the renting price and the mark-up are higher than for the reference case.



We ever observe in this graph a weak decrease of the renting price for a small value for Ω. There are two effects, according to equation [13], the first one is the decrease of construction prices due to the smaller demand; the second one is the increase of the markup. In this case the first is the main one.



The effect on the rate of occupied buildings τ is quite weak.



Conclusion

This paper analyses one fact, the investment report from construction to the enhance of energy efficiency. The conclusions are quite clear. If there is a massive shifting from construction investment, there will be a high pressure on the estate market because of an inadequacy between supply and demand. The person who has the choice to build a flat or to renovate its home will take the second option. It will cause a sudden rise of estate prices, a rent effect that will be responsible for inflation.

This paper is only a door to further studies of the modelling energy efficiency. Some crucial questions need an answer. There must be a model for the trend in green construction. It's obvious that people who renovate buildings know they will enforce a higher renting price, because they know the energy consumption will be smaller. We treated in this paper a model with asymectric information, we need to know how does it work with perfect symetric information.

There also must be a retroaction of the energy efficiency investment to the construction sector. The cost of green buildings, HQE or at positive energy, is higher, about 15% to 30% more than a normal building. And there will be an impact on unemployment because of the new labor and capital intensity linked to these "green" jobs.

Of course, all these results must be interpreted with the most caution we can have. Datas on energy efficiency markets are recent and we are not far enough away to judge about the future of this market.

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