Modeling Telephony Energy Consumption

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Abstract

The energy consequences of rapidly changing telecommunications technology are a significant concern. While interpersonal communication is ever more important in the modern world, the need to conserve energy has also entered the social consciousness as prices and threats of global climate change continue to rise. Only twenty years after being introduced, cellular phones have become a ubiquitous part of the modern world. Simultaneously, the infrastructure for traditional telephones is well in place and the energy costs of such phones may very well be less. As a superior technology, cellular phones have gradually begun to replace the landline but consumer habits and perceptions have slowed this decline from being an outright abandonment. To evaluate the energy consequences of continued growth in cellphone use and a decline in landline use we present a model which describes three processes: landline consumption, cellular phone consumption, and landline abandonment as economic diffusion processes. In addition, our model describes the changing energy demands imposed by the use of the two technologies and considers the use of companion electronics and consumer habits. Finally, we use these models to determine the energy consequences of the future uses of the two technologies, an optimal mode of delivering phone service, and the costs of wasteful consumer habits.

Introduction

In these first few years of the new millennium, energy policy has taken a center ring in political discourse, and considerable time and research has been devoted to developing sound energy policy. Intimately connected to this new drive is an increasing awareness of the impact of our lifestyle habits on energy consumption. The telephone has become a fundamental part of our social fabric, and in the past couple decades we have seen a shift from fixed landline telephones, generally one per household, to individual ownership of cell phones. It is natural to consider what impact this has on American energy consumption, and in this paper we attempt to determine just that. The factors that go in to accurately modeling telephony energy consumption are complex. An accurate picture of the energy used by landline and cell phones needs to take into account energy consumption by peripheral devices, such as answering machines for landline phones and chargers for cell phones. Moreover, landline phones are not a uniform product. Cordless phones consume considerably more energy than their corded counterparts. Likewise, the total energy cost of cell phone usage is complicated by such factors as recharging, replacement, and battery recycling. Our model takes all of these factors into account, and additionally attempts to use the limited real-world data available to chart the changes in each of these factors over time.

Perhaps the most complex factor to model is, most generally, adoption of technological innovations in a population. This is relevant not only to landline adoption and cell phone adoption, but additionally deadoption of landline phones in the face of cell phone usage can be considered an independent innovation amd modeled accordingly. Research into the phenomenon indicates that it can be modeled globally by the differential equation

$$\frac{dP}{dT} = rP\left(1 - \frac{P}{K}\right),$$

where P is the proportion of the considered population which has adopted the new innovation at time t, r is the adoption rate and K is the saturation point for the innovation within a population. A justification of this is given, but an apt summary of the reasoning can be found in this statement:

> Irrespective of the particular account of the diffusion process, the stylized diffusion path of most innovations results from the fact that initially, during an embryonic phase, only a few members of the social system adopt the innovation. Over time, though, an increasing flow of new adopters is observed as the diffusion process unfolds. This is the phase of rapid market growth. Finally, during a maturing phase, the trajectory of the diffusion curve gradually slows down, and eventually reaches an upper asymptote or saturation level.

Using the descriptions of such a model, we arrive at an accurate fit to the available data and are able to predict future demand for cell phones and landlines. Determining the cost for these respective technologies we arrive at the total energy burden. Briefly, we explore how this question relates to the energy consumption of other household electronics, and how much waste is generated therein. Additionally, we explore the caveat that technological development has been and continues to be wildly unpredictable, and the consequences of this reality.

A separate question is to consider how best to distribute landline and cell phones throughout a population committed to neither so as to minimize energy consumption, optimally while not violating social preference. This problem is explored through an optimization with respect to energy usage, in which we discover that a country, here the 'Pseudo-USA', which supports a cell phone-only communicative infrastructure minimizes its total energy consumption, and also does not violate social demand for novel technologies. Finally, we estimate the total energy consumption by such a nation over the next fifty years.

Model Overview

We examine two approaches to modeling technology diffusion through a population. The first attempts to gauge technology adoption at the household level and aggregate these results to model global trends. However, this approach is unsuccessful, and the reasons for this are explained. The second approach models technology adoption at the global level. This model:

1. Accurately models past and present telephony energy consumption,
2. Makes future predictions of cell phone saturation and landline deadoption consistent with previous technological replacement paradigms.
3. Encompasses a broad range of pertinent factors in telephony energy consumption.

Model Derivation

Adoption of Innovations Our model describes the United States' usage rates for landlines and cell phones as three diffusive innovation curves. Consider the adoption of an innovation Y. At small times after the development of this innovation, adoption of Y throughout a population is minimal. As the innovation spreads, demand increases until a saturation point is reached. Thus, the spread of Y throughout a population is proportional to its synchronous prevalence, but is checked from exponential growth by an upper bound to its saturation in a population. At its simplest, we can model this as

$$\frac{dY}{dt} = Y(1 - Y).$$

Of course, adoption is not uniform between different technologies, and saturation rates likewise vary. By introducing constants r for adoption rate and S for saturation rates, we can refine our model to

$$\frac{dY}{dt} = rY(1 - Y/K),$$

which has a solution in form of the logistic equation. Therefore, for each of the processes we assume a model of the form

$$\frac{A}{1 + Be^{-Ct}}.$$

The sigmoidal form assumed by adoption processes is well known and has been observed in the specific case of cellphone adoption and wireless only life-style adoption. Quoting from the literature:

> Several behavioural theories have traditionally been set forth to explain the S-shaped nature of diffusion processes. For example, Griliches (1957) proposed an 'epidemic', demand-induced explanation for the emergence of an S-shaped diffusion curve; Mansfield (1961) sought to explain the observed patterns of diffusion in terms of the expected profitability of the innovation, and the dissemination of information about its technical and economic characteristics; Rogers (1983) employed a communications-based model for explaining diffusion patterns; Artle and Averous (1973), analysing the telephone system, offered a 'network consumption externality' explanation wherein the value of the network for a subscriber increases with the number of adopters of the system.

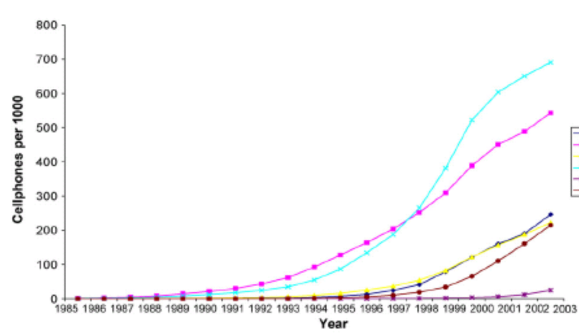

Fig. 2. Average cell phone penetration.

Figure 1: Sigmoidal Growth of Cell Phone Adoption in Various Countries

Proceeding globally, we initially model the consumption of telephones from their inception by the equation:

$$p_l(t) = A\left(\frac{1}{1+Be^{-C(t-D)}} + \frac{1}{1+Ee^{F(t-G)}} - 1\right), \tag{1}$$

where the D and G paramters are chosen so that time is shifted relative to the onset of cell phone adoption. This is essentially the addition of two sigmoid curves. The first models the adoption of the landline phone as a new innovation. We model the deadoption of landlines as an independent innovation of a 'wireless-only' lifestyle, which has a subtractive effect total landline usage.

Likewise the consumption of cellphones is given by:

$$p_c(t) = \frac{J}{1+e^{-K(t-L)}}, \tag{2}$$

where again L is a time shift chosen to make the model coincide with cell phone adoption.

Initial attempts were made to model this at the microscopic level, but this proved to be an intractable approach. From census data, the number of H household with m members over the course of history is readily available. Equally accessible are the rates of penetration and average costs of cellular and land-line communications penetration. With this abundance of data one may be tempted to propose an econometric forecast of telephony usage which is driven by the marginal cost-benefit analysis a household performs. However determining the functional form which defines the behaviors that are muddled by habits and irrationality are troubling. When reduced to a first order approximation such a model still requires the calibration of numerous parameters[KOYCK Citation]. After attempting such an approach several times it was abandoned. We believe the above model captures the data equally well without making undue assumptions.

Energy Cost of Landlines Together these two functions model three processes: landline adoption, wireless adoption, and wireless only adoption. Additionally they describe the long-term behavior of these processes as they reach a steady state. To approach the question of annual energy consumption by telephony products, we combine these functions with models for energy expenditure by landline phones and their peripherals, as well as cell phones and their peripherals. The formula for energy consumption by landline phones and peripherals is

$$E_l(t) = Pp_lh(\pi_a e_a + \pi_b e_b + \pi_c e_c + \pi_d e_d). \tag{3}$$

The following table delineates the variables and their explanations. Note that the time variable t is normalized such that $t = 0$ denotes 1960.

Due to the limitations imposed on the model by a lack of relevant data, several assumptions were made. First, all yearly energy consumption functions are assumed to be constant in time. Because corded phones draw their energy solely from phone lines, there is little room for variation in their power draws, so this at least seems reasonable. However answering machines, cordless phones, and combinations of the two do not have this restriction, and it seems likely that they are becoming more energy efficient with time. However, no data was available to support this hypothesis, so YEC has been fixed based on available sources. The adoption of cordless vs. corded phones and answering machines no doubt follow their own sigmoidal curves, but again no data was available to accurately gauge this. So, the variables $h, \pi_a, \pi_b, \pi_c, \pi_d$ are all modeled as first-order linear

Variable	Description
$P(t)$	Population of the US in year t
$p_l(t)$	Landlines per person in the US
$h(t)$	Handsets per landline
$\pi_a(t)$	Percentage of landline owners with corded phones
$e_a(t)$	Yearly Energy Consumption in kWh (YEC) by corded phones
$\pi_b(t)$	Percentage of landline owners with cordless phones
$e_b(t)$	YEC by cordless phones
$\pi_c(t)$	Percentage of landline owners with combination cordless phone/answering machines
$e_c(t)$	YEC by combination cordless phone/answering machines
$\pi_d(t)$	Percentage of landline owners with separate answering machines
$e_d(t)$	YEC by separate answering machines

Figure 2: Table 1

approximations. Regardless, results produced by the model agree well with available data for energy consumption.

Energy Cost of Cell Phones The energy cost for cell phones is likewise complex. It can be modeled as

$$E_C(t) = Pp_c(E_{c1} + E_{c2}), \tag{4}$$

where

$$E_{c1}(t) = f_C(C_{charge}t_{charge} + C_{standby}t_{standby})$$

and

$$E_{c2}(t) = R_{cell}R(t).$$

The following table lists and describes each relevant variable:

Variable	Description
$P(t)$	Population of the USA in year t
$p_c(t)$	Number of cell phones per person
E_{c1}	YEC by cell phones and chargers
E_{c2}	YEC by cell phone recyclers
f_C	Frequency of cell phone charging
C_{charge}	Charger wattage during charging
t_{charge}	Daily charger time spent charging
$C_{standby}$	Charger wattage during standby
$t_{standby}$	Daily charger time spent in standby
R_{cell}	Energy needed to recycle one cell phone battery
$R(t)$	Percentage of cell phones recycled in year t

Figure 3: Table 2

The most immediate contributions to cell phone energy consumption are charging the phone at home and leaving the charger plugged in the outlet with no phone attached. It proved difficult to find data on cell phone charging frequency. In their 1999 study, Rosen

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et al. argued that people charge their phone 50 times each year at their residence, noting that many people charge their phone in their car. Even when considering the effect of people charging in their car, this figure seems very low. Especially newer phones with a multitude of different features require more frequent charging. Since charging their cell phone has developed into a habit for most people, we decided to assume that people charge their phone every night and keep their charger attached to an outlet all the time.

Another figure we drew from that study is the average charging time for cell phones. Rosen et al. observe that the average time required to charge a cell phone is 2 hours. We note that the 2 hour charging time seems low in comparison to other data we found, which suggested 3 to 4 hours to charge to 80% and an additional 8 hours to charge to 100%. However, since we are assuming that people charge their phones every night, their phones will probably not have an empty battery capacity when they charge them overnight. It also important to note that we are also assuming that the possibility of people charging their phone overnight does not effect the 2 hour charging time. The fact that 50% of all cell phone batteries are Lithium-Ion batteries, which do not allow for overcharging, justifies this assumption (Fishbein and Rosen). Once a Lithium-Ion battery is charged the power being drawn differs negligibly from the power drawn by the charger hen no phone is connected to it (Rosen). Therefore, we feel justified in adopting Rosens statistic.

When modeling the energy cost of recycling used cell phone batteries, we only considered the batteries being recycled by the Rechargeable Battery Recycling Corporation. This assumption is justified by their significant market share and the fact that we could confirm that the Rechargeable Battery Recycling Corporation recycles their batteries in the United States.

Energy Optimization Given the above functions which give the energy costs for cellular and land-line telephone usage, it is possible to optimize the delivery of these communication methods so that energy consumption is minimized. Consider a pseudo-USA with the approximate size of the United States. It is likely that such a population would have a similar distribution of households by household size as the current United States. Here the average household size is small and there are very few families with more than seven members. Indeed it is the case that many other modern countries have very similar average household sizes which are centered near 2-3 members. Let H_m be the number of households with m members. Then let l_m be the fraction of households with m members which have a land-line service. If we assume that the communication needs of every family are satisfied by either having a land-line or by each member possessing a cellphone, the number of required cellphones and land-line phones can be simply calculated as follows:

$$T_l = \sum_{m=1}^{7} l_m H_m, \tag{5}$$

$$T_c = \sum_{m=1}^{7} m(1 - l_m) H_m, \tag{6}$$

where T_l is total number of landlines and T_c is total number of cell phones.

We believe it is justified that in the absence of a landline every member that members of a household will not share one cellphone as this corresponds well to the authors' everyday experiences.

Then given the cost functions $E_l(t), E_c(t)$, we can calculate the total telephony energy demand of the proposed plan for pseudo USA as:

$$E(t) = E_l(t) + E_c(t).$$

Clearly using only landlines will minimize the number of telephone units required for a population, however landline phones and their companion technologies are much less energy efficient than cellular phones. Simultaneously utilizing only cellphones will maximize the number of telephone units required for a population, and though the energy cos per unit is reduced, the overall increase in units may have deleterious consequences. Therefore we may proceed by an optimization of the variables l_m's which will then yield the best communications strategy from an energy perspective. Additionally, it is possible to modify the above summations to consider the fact that there may be roles played by cellphones which are not achievable by a landline. For example, suppose it is the case that a single landline cannot serve a large family. If n is the number of people a single landline can serve in a household, we may assume that a family of m with one landline will need to purchase $m - n$ cellphones. Then,

$$T_c = \sum_{m=1}^{7} m(1 - l_m)Hm + \sum_{m=n+1}^{7} l_m H_m(m - n),$$

where the second term gives the fraction of families too large to be served by their single landline. Implicit in this formula is an assumption that no family obtains a second landline to meet their communications needs. This is reasonable as the average number of landlines per household in the current United States is only 1.118. Likewise we could further complicate the cost function for a proposed plan for communication by asserting that not every family member requires a cellphone if a landline is absent. However we found that such a modification did not enrich the conclusions of our optimization.

Results

Energy Consumption Using the above information, we can create an energy consumption function $E(t)$. Specifically,

$$E(t) = E_c(t) + E_l(t). \tag{7}$$

To do so, we first had to derive exact parameters for equations (1) and (2). Using an optimization algorithm described in the methods section below, we arrived at the conclusions listed in this table:

Parameter	**Value**
A	1.1263
B	1.0924
C	0.0423
D	27
E	0.0109
F	0.1587
G	30

Figure 4: Table 3

Moreover, functions can be described for parameters for E_l and E_c as follows:

Variable	Value
$P(t)$	Population growth as predicted by the Census Bureau
$p_l(t)$	As defined in Eq(1)
$h(t)$	$1.89\text{E}^{-3}t + 1.076$, $t \leq 40$; $-1.20\text{E}^{-3} + 1.152$, $t > 40$
$\pi_a(t)$	$1 - \pi_b(t) - \pi_c(t)$
$e_a(t)$	20 kWh
$\pi_b(t)$	$\max(0{,}1.45\text{E}^{-2}t - 1.45\text{E}^{-1}),t \leq 40$; $.44,t > 40$
$e_b(t)$	28 kWh
$\pi_c(t)$	$\max(0{,}1.07\text{E}^{-2}t - 1.07\text{E}^{-1}),t \leq 40$; $.32,t > 40$
$e_c(t)$	36 kWh
$\pi_d(t)$	$\max(0{,}2.31^{-2}t - 2.31\text{E}^{-1}),t \leq 40$; $.69,t > 40$
$e_d(t)$	36 kWh

Figure 5: Table 4

Variable	Value
$p_c(t)$	As defined in Eq(2)
E_{c1}	$.365(4 \cdot 2 + .6 \cdot 24)$ kWh
E_{c2}	$-0.0283e^{\frac{-(t-1993)}{17.1573}} + 0.00037$ kWh
f_C	365
C_{charge}	4 W
t_{charge}	2 hr
$C_{standby}$	0.6 W
$t_{standby}$	24 hr
R_{cell}	.0037 kWh
$R(t)$	$-7.639e^{\frac{-(t-1993)}{17.1573}} + 0.0999$

Figure 6: Table 5

From our model, it is expected that by 2050, cell phones will have completely replaced landlines in the USA. Thus, we can estimate our steady-state energy consumption as $E(90) = 2.99$ TWh, which is equivalent to 1.7 million barrels of oil, using a conservative population estimate.

Energy Optimization Results From our optimization results for the distribution of telephone types in the Pseudo-USA, we find that it is almost always preferable to have a cell phone-only state, in terms of energy efficiency. Even assuming a landline can service an unlimited number of people in a household, our optimization finds that it is only energy efficient for families of size 7 or larger to own a single landline and peripherals in place of a cell phone for each family member. In the case that a landline can only effectively service six people in a household, a reasonable assumption, our optimization finds that it is always preferable for a household to purchase a cell phone for each member.

Additionally, we find that the cost of leaving cellphone chargers on standby whenever they are not active would amount to approximately 62% of the total YEC, which amounts to 862000 barrels of oil a year.

Energy Waste by Other Household Electronics We also discuss the impact of leaving devices plugged in when the device is not in use. From Rosen et al., we adopt the following approach to the model. First, we investigate the average wattage used in standby mode by the devices under consideration and the time spent in standby mode, respectively. Then, we find saturation and penetration values to find the total energy expenditure in the current United States. The devices we consider are the computer, TV, set top boxes (digital and analog), wireless set top boxes and Video Game Consoles.

We took the data for the three types of set top boxes and the video console data from Rosens study. Furthermore, the average American spends an average of 4.66 hours watching television and 4.4 hours using a computer every day . Average power drawn by computers and television sets turns out to be 4 and 5.1 watts respectively. The table illustrates our data set.

Device	**Standby Time**	**Power Drawn** (W)
Set Top Box, Analog	78%	10.5
Set Top Box, Digital	.78	22.3
Wireless Receiver	.78	10.2
Video Game Console	.98	1.0
TV	.80	5.1
Computer	.81	4

Figure 7: Table 6

We can then use this information, along with saturation rates and household penetration rates to arrive that the following conclusion:

Device	**Standby Energy Consumption** (TWh)
Cable, Analog	3.2
Cable, Digital	0.6
Wireless Receiver	1.4
Video Game Console	0.5
TV	10.3
Computer	3.3
Total	**19.3**

Figure 8: Table 7

Using this final figure in Table 7, we conclude that wasteful energy expenditure due to appliance standby in the USA consumes approximately 11.4 million barrels of oil yearly.

Future Predictions By our model, assuming moderate economic and population growth, the following figures were determined for the Pseudo-USA:

Year	**Energy Costs** (millions of barrels of oil)
2010	1.14
2020	1.24
2030	1.66
2040	1.77
2050	1.89

Figure 9: Table 8

However, we believe that such an analysis is of highly limited use. Predicting the future of so many variables for a 50 year period is extremely difficult especially in the realm of technology where it is common-place for innovations to change social paradigms. For example consider an attempt in the 1950's to model the growth of computer usage. Any such attempt would be unlikely to foresee the occurrence of personal computers,the Internet, or cellphones which today are rapidly replacing many of the functions of personal computers. Likewise the energy cost of a cellphone may very plausibly vary greatly due to changes in technology. It may be the case that social awareness about energy efficiency will drive them to become even more energy cost effective. It is equally likely that cellphones will gain additional features or be replaced by miniaturized computers which consume much more energy. Therefore the above prediction can only be regarded as relevant in the state of affairs where "all other things" are equal. In the sphere of technological growth "all other things" is very broad and the assumed stagnation is unlikely.

Conclusions

Recommendations

From and energy perspective we find that it is without a doubt more efficient to abandon landlines in favor of cell phones. This sugguestion is reinforced by the model prediction which sugguests an elimination of landlines in the near future by consumer adoption of a wireless-only lifestyle. Finally we find that the waste generated by chargers on standby (ie. not charging a device) are a significant source of energy waste. We therefore advocate that efforts be made to forgoe convenience and unplug devices when in standby.

Model Strengths and Weaknesses:

Strengths: -reproduces sigmoidal innovation-adoption behavior without making undue assumptions about the underlying processes -incorporates a broad span of indirect sources of energy consumption: battery recycling, commuters with cellphones, landline companion technologies

Weaknesses -Our model only captures global adoption behavior. This exclusion of underlying behavior is a detriment in capturing the deviations from the standard behavior This is exemplified by the underestimation in the 90's during which economic expansion may have driven telephone adoption

-Due to a lack of data the model relies on interpolation of data related to cellphone and landline energy costs

- For simplicity the model excluded other possible communications technologies. As noted earlier, paradigm shifts in technology are commonplace yet hard to predict -excludes other communications technologies

-The model fails to capture any benefit of landlines not provided by cellphones. It may be that landlines are associated with a certain degree of security which mediates the current prediction that landlines will be completely abandoned.

Future Work - Though we found it problematic and frustrating, we believe a model which acts at the microscopic level and takes into consideration consumer perceptions and habits in addition to economic data would perform the best.

-We also believe modelling cellphones and landlines as more directly competing products with reference to economic data would provide better data fits and predictions

-The above analysis was limited to the household level. Landline phones persist in many businesses and we believe this will be a significant factor in energy consumption.

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{
opt.m
maxt=50000;
maxl=1000000;
sum=0;
sum0=-1;
tick=0;
lim=0;
change=0;

for k = 1:47
    sum=sum+((parms0(1)*(1/(1+parms0(2)*exp((-parms0(3)*(x(k)-27))))+1/(1+parms0(5)*exp((parms0(4
end
sum


while ((sum>.0001) || (abs(sum-sum0)>.001))
    if (tick >= maxt) || (lim >= maxl)
        disp('Limit Reached')
        change %#ok<NOPTS>
        break
    end
    parm=max(.5,6*rand(1,1))*sqrt(sum)/30;
    var=2*parm*rand(1,1)-parm;
    n=floor(.5+4*rand(1,1));
    parmb0=parms0;
    sum0=sum;
    sum=0;

    if n == 0
        parms0(2)=parms0(2)+var/10;
    end
    if n == 1
        parms0(4)=parms0(4)+var/100;
    end
    if n == 2
        parms0(1)=parms0(1)+var;
    end
    if n == 3
        parms0(3)=parms0(3)+var/100;
    end
    if n == 4
        parms0(5)=parms0(5)+var/10;
    end

    for j = 1:48
        sum=sum+((parms0(1)*(1/(1+parms0(2)*exp((-parms0(3)*(x(j)-27))))+1/(1+parms0(5)*exp((parm
    end
    if sum >= sum0
        parms0=parmb0;
        sum=sum0;
    else
        tick=0;
```

```
        change=change+1;
        sum %#ok<NOPTS>
    end
    tick=tick+1;
    lim=lim+1;
end

opt1.m
max=10000;
maxl=1000000
tick=0;
lim=0;
change=0;
sum=0;
sum0=-1;

for j=1:41
    sum=sum+(tele(x(j),parms)-y(j))^2;
end

while ((sum>10^(-5)) || (sum-sum0<10^(-9)))

    if (tick >= max) || (lim >= maxl)
        disp('Limit Reached')
        change %#ok<NOPTS>
        break
    end

    sum0=sum;
    parmb=parms;
    p=sqrt(sum)/30;
    var=p*(2*rand(1,1)-1);
    n=floor(1+3*rand(1,1));

    if n == 1
        parms(n)=parms(n)+var;
    end
    if n == 2
        parms(n)=parms(n)+var/100; %#ok<*AGROW>
    end
    if n == 3
        parms(n)=parms(n)+var;
    end
    sum=0;
    %parms
    for k=1:41
        sum=sum+(tele(x(k),parms)-y(k))^2;
    end
    if sum>=sum0
        parms=parmb;
        sum=sum0;
    else
        tick=0;
```

```
        change=change+1;
    end
    tick=tick+1;
    lim=lim+1;
    sum %#ok<NOPTS>
end
```

opt2.m

```
max=10000;
maxl=1000000;
lim=0;
tick=0;
change=0;
sum=0;
sum0=-1;

for j=1:19
    sum=sum+(celle(x1(j),parms1)-y1(j))^2;
end

while ((sum>10^(-5)) || (sum-sum0<10^(-9)))

    if (tick >= max) || (lim>=maxl)
        disp('Limit Reached')
        change %#ok<NOPTS>
        break
    end

    sum0=sum;
    parmb1=parms1;
    p=sqrt(sum)/10;
    var=p*(2*rand(1,1)-1);
    n=floor(1+3*rand(1,1));

    if n == 1
        parms1(n)=parms1(n)+var;
    end
    if n == 2
        parms1(n)=parms1(n)+var/1000; %#ok<*AGROW>
    end
    if n == 3
        parms1(n)=parms1(n)+var;
    end
    sum=0;
    %parms
    for k=1:19
        sum=sum+(celle(x1(k),parms1)-y1(k))^2;
    end
    if sum>=sum0
        parms1=parmb1;
        sum=sum0;
    else
```

```
        tick=0;
        change=change+1;
    end
    tick=tick+1;
    lim=lim+1;
    sum %#ok<NOPTS>
end
```

opt3.m

```
max=10000;
maxl=1000000;
lim=0;
tick=0;
change=0;
sum=0;
sum0=-1;

for j=1:47
    sum=sum+(tele(x(j),parms)+detele(x(j),parms2)-y(j))^2;
end

while ((sum>10^(-5)) || (sum-sum0<10^(-9)))

    if (tick >= max) || (lim>=maxl)
        disp('Limit Reached')
        change %#ok<NOPTS>
        break
    end

    sum0=sum;
    parmb2=parms2;
    p=sqrt(sum)/10;
    var=p*(2*rand(1,1)-1);
    n=floor(1+3*rand(1,1));

    if n == 1
        parms2(n)=parms2(n)+var;
    end
    if n == 2
        parms2(n)=parms2(n)+var/1000; %#ok<*AGROW>
    end
    if n == 3
        parms2(n)=parms2(n)+var;
    end
    sum=0;
    %parms
    for k=1:47
        sum=sum+(tele(x(k),parms)+detele(x(j),parms2)-y(k))^2;
    end
    if sum>=sum0
        parms2=parmb2;
        sum=sum0;
```

```
    else
        tick=0;
        change=change+1;
        sum %#ok<NOPTS>
    end
    tick=tick+1;
    lim=lim+1;
end
```

celle.m

```
function C=celle(x,parms)
%cellphone adoption function

if x<29
    C=0;
else
    C=parms(1)./(1+exp(-parms(2).*(x+parms(3))));
end
```

parms0.m

```
[1.126346841186298,1.092443438718643,0.042304296551599,0.158692053851258,0.010864436027023]
```

parms1.m

```
[0.929052472290896,0.295494950200304,-42.973887435250440]
```

Code for optimization of energy in Pseudo USA

```
#####################################################################
function C=Cost(par,Hm,Cl,n)
%landline can only serve n members

T=sum(par.*Hm);
Cn=sum((1:7).*(1-par).*Hm);

Cn=Cn+sum(par(n+1:end).*Hm(n+1:end).*(1:7-n));

C=Cl*T+cellenergynew(Cn,2009);

%
function [ce] = cellenergynew(n,t)
% function to calculate the energy consumed by cell phones, given the n
% cell phones in use at some time t
ce = (n)*(8.176)+ n*((.021)*(-0.07639)*exp((-t+1993)/17.1572)+0.1139);
#####################################################################
C=10^20; par=rand(1,7);best=par; changes=0;Cl=49.9880;Cc=11.096;r=7;
tic
for k=1:100000
    n=1+floor(7*rand);
    par(n)=rand;
    cost=Cost(par,Hm,Cl,r);
```

```
    if cost<=C(end)
        best=par;
        C=[C cost];
        changes=changes+1;
    else
        par=best;
    end
end
toc
plot(C(2:end))}
```

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