An Agent Based Model of the Housing Market: HousingMarketRev8.3.nlogo

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Abstract[1]

In this paper we present a simple agent based model of the housing market that we have built in NetLogo, where only the interest rates are set exogenously and the experiments are run according to the actual historical interest rates from the US. The results of these experiments are consistent with the bubble burst from middle 2007. This is a level 1 type of model performance, where running the different scenarios and experiments leads to the observation of some emergent phenomena with respect to the foreclosures and the average house prices that qualitatively match the trends that we observed in reality.

Keywords: housing market, agent based modeling, NetLogo, interest rate, economic bubble, level 1 model performance

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1. Introduction

The NetLogo model built here represents an agent based model of a conceptual/theoretical housing market, where the prices of the houses and the mortgages are determined endogenously by the interacting agents (people and banks) in the model, while shocks are induced only by controlling for the interest rates exogenously.

The premise for developing this model was the current financial crisis and the housing market bubble of 2008-2009, particularly in the USA. The common view of economists with respect to the housing bubble causes is that the Federal Reserve policies and measures that started in 1993 with respect to interest rates has led to the current crisis.

By building this simple model, we try to verify this hypothesis or at least to observe some emergent properties in the housing market. This is a level 1 Axtell-Epstein (1994) type of model, where we observe patterns of development out of the individual interactions of agents qualitatively and try to match them with the empirical data.

In Part 2, we describe the actual model: the landscape, the conceptual framework, the agents and the model calibration and plots. In Part 3, we describe how we have run the model with the scenario of the real interest rates set by the Federal Reserve from 1993 until 2009 on a monthly (tick-by-tick) basis and we discuss the results. In Part 4, we conclude with a statement for further developments.

2. Model Description

This model is based on a simple instantiation of the real-world housing market. Using the generative characteristic of agent-based modeling, the model uses a bottom-up approach by utilizing the dynamic relationships between interest rate changes and demand and supply on house prices that will, under certain circumstances, cause the house bubble to emerge. For simplification purposes, the housing construction market is feigned by initializing many more houses for sale and for rent than the number of people. Mortgages are Adjustable Rate Mortgages

(ARMs) based on interest rate. Investment houses are assumed to be purchased for appreciation only, rather than to increase income. Thus, incomes are static.

The model uses the NetLogo platform and is based on a 32 by 32 grid. The main components of the model are People, Houses, Banks, and Mortgages. People agents are either renters or owners of one or more houses. Each house is associated with zero or one mortgage that is owned by a bank.

The following UML diagram illustrates the main agent blocks in the model, the interdependent relationships between them, and the basic attributes of each.

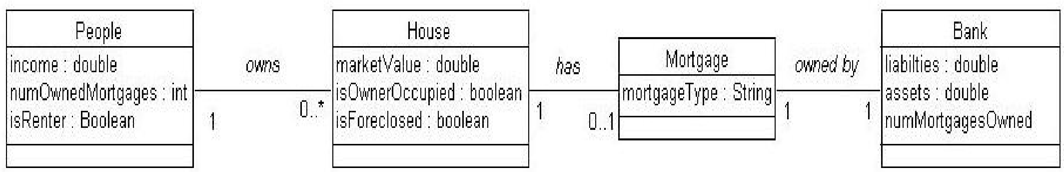

Figure 1: Class diagram of the model describing its entities, their relationships, and attributes

To provide a more elaborate picture of model dynamics, following is a detailed description of each component and its behavior (if applicable).

People

As the principal agents in the model, people have annual fixed income that follows a uniform random distribution ranging between 5-15 K. The gradient green color of people reflects the differences in income level—the darker the shade, the wealthier the agent.

The model underlies a structured process of agents' relocation and attribution to rented and owned houses. At each time step each agent evaluates its financial state and bases relocation decision as well as handling rent or ownership situation accordingly. At the initialization of the model, an agent evaluates whether it can buy a house as a primary residence. If the available investment capital is insufficient, it evaluates for renting a house instead. If it can afford to rent, it relocates to a random affordable rental, otherwise it exits the system. If the agent can afford to buy a primary residence house, it relocates to one. If a house owner can not afford paying mortgages on the house, it evaluates for renting. House owner systematically evaluate whether they can afford buying an extra house for investment (renting out for other agents). Moreover, if an agent owns more than one house and can no longer afford paying the mortgages, it randomly picks a house from the list of houses it owns and sells it.

Lastly, the expected time for staying in the same house is set at 7 years (84 ticks during the run of simulation); *i.e.* agents move every 7 years on average. Figure 2 illustrates the aforementioned decision structure in details.

With respect to people's response to changes in interest rate, a lag effect has been introduced in order to dampen the effect of an immediate global response and hence the counterintuitive appearance of too many foreclosures at low levels of interests rates. This is considered one of the modifications implemented on the current version of the model in comparison with the previous one.

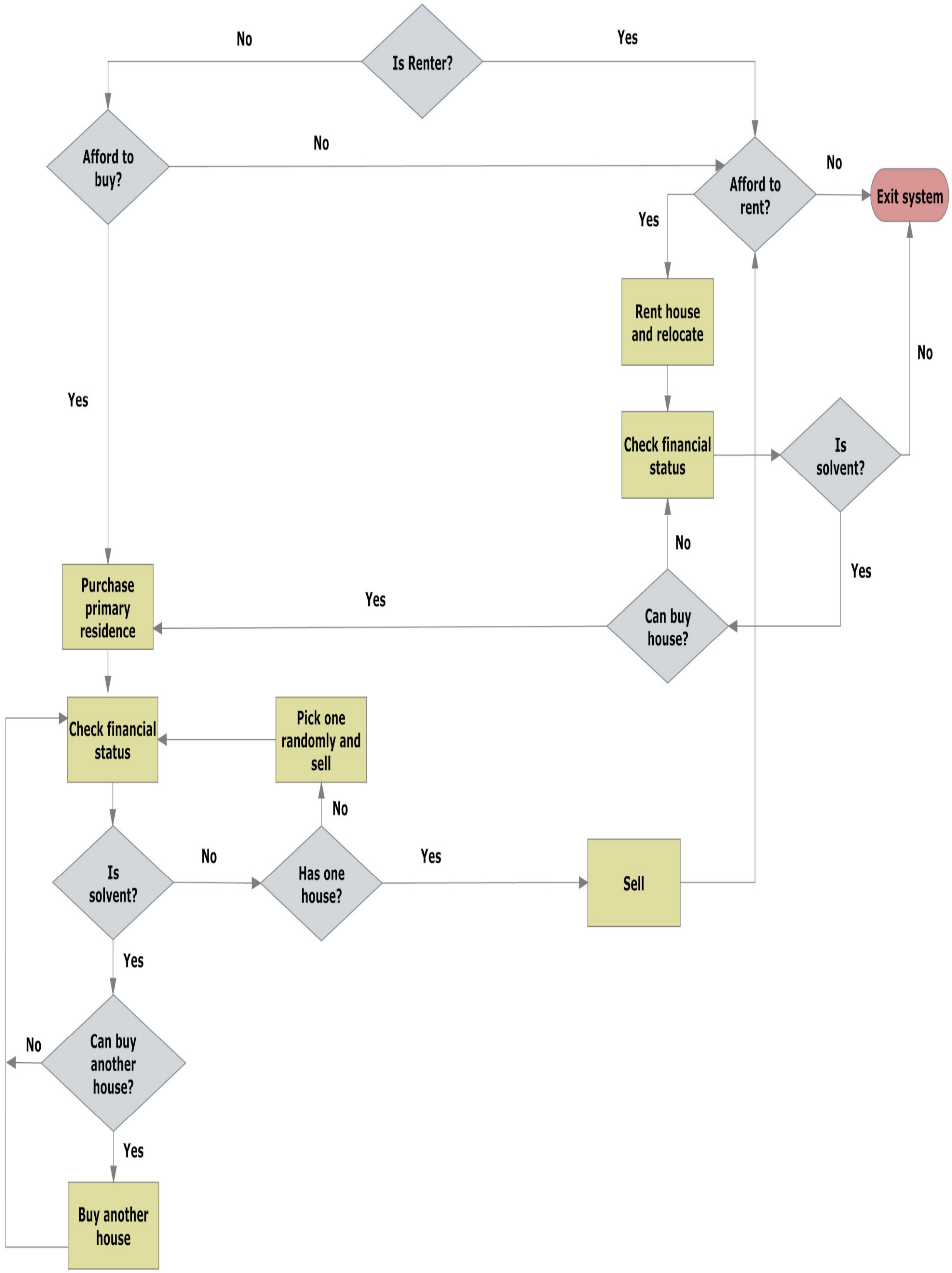

Figure 2: A flow chart describing the decision-making model of agents' behavior and the possible transition between renters and owners populations.

Houses

The model assumes that initial house prices also follow a random uniform distribution within the range of 75-150K. Red patches indicate rental houses, while blue ones are for ownership.

Again, darker shades of either color indicate higher mortgage cost or rent. Black patches are assigned as empty. For rental houses, a simple function is used to determine rent price:

$$\text{rent} = \text{house price} \times \text{fractional constant}$$

The effect of aggregate demand on prices in a financial market model was described by Rama Cont's formula (2005):

$$r_t = \ln \frac{S_t}{S_{t-1}} = g\left(\frac{Z_t}{N}\right)$$

where:

r_t: return on house price at time t

S_t: house price at time t

Z_t: excess demand for houses at time t

N: number of agents

With $g(x) = x$, house price appreciation or depreciation, can be expressed in terms of excess demand, i.e. by solving for S_t.

One important departure of the current from the previous one is on the perspective of foreclosures. The original model considered foreclosures occurring in the account of owners who sell their houses or renters who move out due to insufficient funds to pay mortgages or rents. However, the current model alters this misleading perception and accounts houses as foreclosed and not the people who sell or leave them. For visualization purposes, a house put on sale turns into pink as an indication of foreclosure.

Mortgages

Mortgages are formulated as agents to capture object-oriented notion that a mortgage is an entity unto itself: the mortgage is owned by (and housed within) a bank, yet is associated with a particular person and also with a particular house.

As people response to changes in interest rate has been modified by a lag effect, mortgage payments have also been modified so that only a random percentage of mortgages respond to changes in interest rate. This is to represent the notion of Adjustable Rate Mortgages (ARMs) that respond to changes in interest rate with a lag effect in consideration.

Banks

In our previous model design, banks were assumed to be 'virtual' owners of the mortgages. In the current improvement of the model, the banks balance sheets are introduced to keep track of their assets and liabilities. The liabilities side of the balance sheets comprises the whole mortgage value of the houses owned by a bank. Banks assets, on the other hand, include monthly mortgage payments investments returns that are assumed to be exogenous to the model (for simplicity). Consequently, in case of a house foreclosure, the owner bank is negatively affected on the side of its assets.

Model Calibration and Plots

The model is initiated by creating houses at a specified density on the map; using 'Initial density of patches' parameter). Each house is then assigned a price within the specified range. Based on the 'Rental House Density' parameter, a fraction of houses are assigned as rentals. 'Percent occupied' parameter determines the number of initialized people on landscape. Each person is then assigned an income level within the specified range. People are assigned to houses according to a matching between their income and mortgage cost/rent level.

There are six main output plots in the model: average house Price, average mortgage cost, number of owned vs. rented houses, banks balance sheet, and percentage of bankrupt people, and average location of houses. The last is computed by averaging the Y-coordinate values of occupied houses. See Figure 3 for a snapshot view of the model initialization.

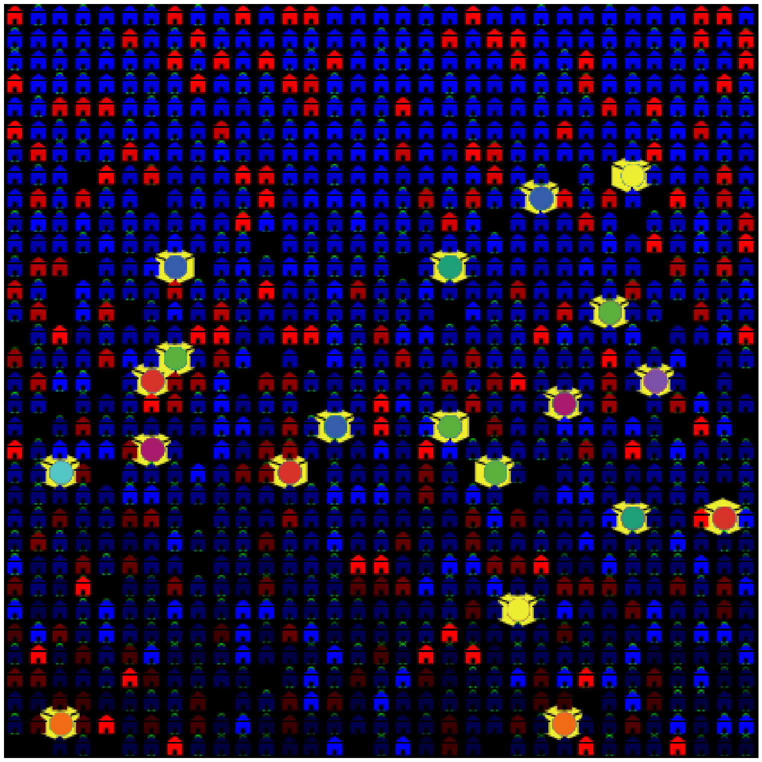

Figure 3: A typical initialized model view of 'HousingMarket'

3. Scenario – running the model with the empirical data

We start by running the interest rates using the real time series of the Federal Reserve from 1993 to April 2009. We have run the model several times and we have observed the following results. In our observations, we mostly targeted the emergent foreclosures, bank bankruptcies and the fluctuations in the prices of the houses.

The increase in the interest rate leads to many foreclosures naturally, as the increase leads to an increase in the average house prices and there is a larger pool of people that do not afford the houses any more. Our target is to see if we observe the occurrence of foreclosures at low interest rates, where supposedly all people afford the houses and we should not observe them.

We are also keeping in mind the fact that we have two random lags introduced in the model, after a few ticks on any constant interest rate, the model equilibrates and we do not observe foreclosures or variations in the prices of the houses.

Initially, we do not observe any emergent phenomenon. Only at the interest rate of 4 (in 1994), we start to observe foreclosures. When we increased the interest rate even further, we don't observe foreclosures any more (over the entire 1994 year). At the interest rates of 6 and 5 (in year 1995) we start to observe more foreclosures again.

When we decreased the interest rate, according to 1996 data, we observed more foreclosures. After we fluctuate the interest rate around the value of 5.5% (1997-1998), we don't observe any more foreclosures as the system adjusts, as expected.

Decreasing gradually the interest rate from the 5% to 2% (from 1998 to 2001), we observe the complete disappearance of the foreclosures. But what we also observe here is that, through the rental/ownership ratio, that less people afford more houses; it is just the people with higher income that afford more houses and offer them for rent. From the economic point of view, this is inconsistent with the fact that more people can afford to buy houses; instead, people with higher income have the incentive to buy more of the so-called "investment houses" and offer them for rent.

When we increase the interest rate from 1 to 3 % (2003-2005), only at the 3.5% interest rate we start to observe the foreclosures again, which otherwise we would not have taken place.

At the 4.5% interest rate, the number of foreclosures increases, as expected – higher interest rate, higher house price. At the value of 5%, the number of foreclosures is very high (around mid 2006). At 5.25% interest rate, at mid 2007, we observe the highest number of foreclosures and a drop in the house average price – which practically means that the bubble burst.

The observed foreclosures until mid 2007 (after approximately 170 ticks/months) are mostly linked to an increase in the price of the houses. Only in mid 2007 we observe the occurrence of foreclosures at decreasing housing prices.

Decreasing the interest rate gradually from 4% to 2% in 2008, we observe less and less foreclosures. Lowering the interest rate even more to values close to zero (for the first months of 2009), we don't observe foreclosures any more, but the average house price increases, as well as the banks go bankrupt (see snapshots below).

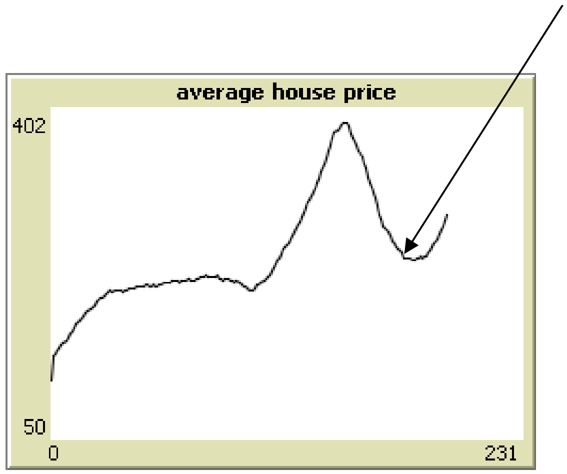

Figure 4: Plot of average house prices throughout the simulation run with the peak taking place around mid 2007

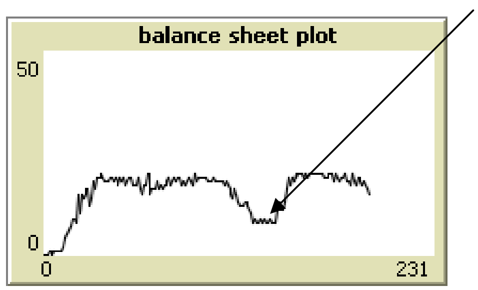

Figure 5: A plot depicting banks balance sheets throughout the model run.

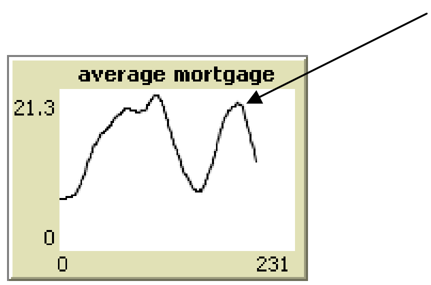

Figure 6: Plot of average mortgage rates. Note the fluctuating pattern compared to average house price plot.

The figures/snapshots above are plots of the behavior of the model throughout the entire scenario 1993-2009. The big drop in the balance sheets corresponds to the big decrease in the house prices and the increase in the mortgage rates (pointed by the arrows). This is the peak of the bubble burst, which is followed by a period of readjustment. In this sense and the level 1 type of model sense, we may say that the emergent phenomena of the model matched the empirical historical data.

4. Conclusions

Building this simple conceptual model and running the model experiment according to the real data from the US history of the interest rate policies, our conclusions are that a policy of controlling exogenously for the interest rates even in a very simple market leads to the emergence of bubbles and foreclosures. The lags and slow adjustments are extremely important for the causes of the bubbles, as in the real world prices do not adjust instantaneously to external shocks. Nevertheless, as we observed the bubble burst at the same period of time (mid 2007/170 ticks) for each time we ran the model according to the same scenario, this leads us to the conclusion that this exogenous control for the interest rates was one of the factors that led to the housing crisis. On the other hand, this is just a necessity, but not a sufficiency condition, meaning that for a level 2 type of model, the subprime crisis should be linked to the housing market.

In comparison to the previous version of the model, we do not observe as similar the model dynamics, due to some coding artifacts that have been corrected in the current version. We believe that the new version approaches reality more than the old version in terms of more realistic realizations of the housing market and of the bubble burst. Nevertheless, the model can be further enhanced by including the supply side of the market represented by the construction companies, in order to refine the endogenous emergence of the house prices.

In conclusion, we believe that due to the thorough coding and conceptual-theoretical framing of this market, the runs and scenarios are closer to evidence in the qualitative patterns. Our focus has been particularly on this thorough conceptual-theoretical building of the model so that the runs and scenarios to be clean and possible under any variety of interest rate fluctuations and to give important and thorough interpretations of the emergent phenomena.

Annex – The interest rate time series

Year	*Month*	**Interest rate**
1993	*1*	**3**
1993	*2*	**3**
1993	*3*	**3**
1993	*4*	**3**
1993	*5*	**3**
1993	*6*	**3**
1993	*7*	**3**
1993	*8*	**3**
1993	*9*	**3**
1993	*10*	**3**
1993	*11*	**3**
1993	*12*	**3**
1994	*1*	**3**
1994	*2*	**3.25**
1994	*3*	**3.25**
1994	*4*	**3.50**
1994	*5*	**4**
1994	*6*	**4.25**
1994	*7*	**4.25**
1994	*8*	**4.5**
1994	*9*	**4.5**
1994	*10*	**4.5**
1994	*11*	**5.25**
1994	*12*	**4.5**
1995	*1*	**5.5**
1995	*2*	**6**
1995	*3*	**6**
1995	*4*	**6**
1995	*5*	**6**
1995	*6*	**6**
1995	*7*	**5.75**
1995	*8*	**5.75**
1995	*9*	**5.75**
1995	*10*	**5.75**
1995	*11*	**5.75**
1995	*12*	**5.5**
1996	*1*	**5.5**
1996	*2*	**5.25**
1996	*3*	**5.25**

1996	*4*	**5.25**
1996	*5*	**5.25**
1996	*6*	**5.25**
1996	*7*	**5.5**
1996	*8*	**5.25**
1996	*9*	**5.25**
1996	*10*	**5.25**
1996	*11*	**5.25**
1996	*12*	**5.25**
1997	*1*	**5.25**
1997	*2*	**5.25**
1997	*3*	**5.25**
1997	*4*	**5.5**
1997	*5*	**5.5**
1997	*6*	**5.5**
1997	*7*	**5.5**
1997	*8*	**5.5**
1997	*9*	**5.5**
1997	*10*	**5.5**
1997	*11*	**5.5**
1997	*12*	**5.5**
1998	*1*	**5.5**
1998	*2*	**5.5**
1998	*3*	**5.5**
1998	*4*	**5.5**
1998	*5*	**5.5**
1998	*6*	**5.5**
1998	*7*	**5.5**
1998	*8*	**5.5**
1998	*9*	**5.5**
1998	*10*	**5**
1998	*11*	**4.75**
1998	*12*	**4.75**
1999	*1*	**4.75**
1999	*2*	**4.75**
1999	*3*	**4.75**
1999	*4*	**4.75**
1999	*5*	**4.75**
1999	*6*	**4.75**
1999	*7*	**5**
1999	*8*	**5**
1999	*9*	**5.25**

1999	*10*	**5.25**
1999	*11*	**5.5**
1999	*12*	**5.25**
2000	*1*	**5.5**
2000	*2*	**5.75**
2000	*3*	**5.75**
2000	*4*	**6**
2000	*5*	**6.25**
2000	*6*	**6.5**
2000	*7*	**6.5**
2000	*8*	**6.5**
2000	*9*	**6.5**
2000	*10*	**6.5**
2000	*11*	**6.5**
2000	*12*	**6.5**
2001	*1*	**6**
2001	*2*	**5.5**
2001	*3*	**5.25**
2001	*4*	**4.75**
2001	*5*	**4.25**
2001	*6*	**4**
2001	*7*	**3.75**
2001	*8*	**3.5**
2001	*9*	**3**
2001	*10*	**2.5**
2001	*11*	**2**
2001	*12*	**1.75**
2002	*1*	**1.75**
2002	*2*	**1.75**
2002	*3*	**1.75**
2002	*4*	**1.75**
2002	*5*	**1.75**
2002	*6*	**1.75**
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2002	*11*	**1.25**
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2003	*1*	**1.25**
2003	*2*	**1.25**
2003	*3*	**1.25**

2003	*4*	**1.25**
2003	*5*	**1.25**
2003	*6*	**1.25**
2003	*7*	**1**
2003	*8*	**1**
2003	*9*	**1**
2003	*10*	**1**
2003	*11*	**1**
2003	*12*	**1**
2004	*1*	**1**
2004	*2*	**1**
2004	*3*	**1**
2004	*4*	**1**
2004	*5*	**1**
2004	*6*	**1**
2004	*7*	**1.25**
2004	*8*	**1.5**
2004	*9*	**1.5**
2004	*10*	**1.75**
2004	*11*	**2**
2004	*12*	**2**
2005	*1*	**2.25**
2005	*2*	**2.5**
2005	*3*	**2.5**
2005	*4*	**2.75**
2005	*5*	**3**
2005	*6*	**3**
2005	*7*	**3.25**
2005	*8*	**3.5**
2005	*9*	**3.5**
2005	*10*	**3.75**
2005	*11*	**4**
2005	*12*	**4**
2006	*1*	**4.25**
2006	*2*	**4.5**
2006	*3*	**4.5**
2006	*4*	**4.75**
2006	*5*	**5**
2006	*6*	**5**
2006	*7*	**5.25**
2006	*8*	**5.25**
2006	*9*	**5.25**

2006	*10*	**5.25**
2006	*11*	**5.25**
2006	*12*	**5.25**
2007	*1*	**5.25**
2007	*2*	**5.25**
2007	*3*	**5.25**
2007	*4*	**5.25**
2007	*5*	**5.25**
2007	*6*	**5.25**
2007	*7*	**5.25**
2007	*8*	**5**
2007	*9*	**5**
2007	*10*	**4.75**
2007	*11*	**4.5**
2007	*12*	**4.25**
2008	*1*	**4**
2008	*2*	**3**
2008	*3*	**2.5**
2008	*4*	**2.25**
2008	*5*	**2**
2008	*6*	**2**
2008	*7*	**2**
2008	*8*	**2**
2008	*9*	**2**
2008	*10*	**1**
2008	*11*	**0.5**
2008	*12*	**0.1**
2009	*1*	**0.1**
2009	*2*	**0.2**
2009	*3*	**0.1**

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