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GREEN REFORM

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A technical note

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1 Introduction

GreenREFORM is intended to be used to assess the societal costs of meeting the government's target of reducing Denmark's net greenhouse gas emissions by 70% compared to 1990 by 2030. It is therefore crucial to have a well-defined measure for this type of cost. It is essential to be able to measure the total costs of such a transformation of the Danish economy, but it is also important to be able to compare the deadweight loss of different policy measures.

The goal is to establish a theory-based welfare measure, as known from Sørensen (2014), Goulder & Williams (2003), and Kleven & Kreiner (2006). The choice of modeling strategy for households consumption and savings in GreenREFORM is influenced by this. We want to have households in GreenREFORM that have both good short-term and long-term properties, and that are specified in such a way that an welfare measure can be derived.

Therefore, it has been chosen to have two types of households: rational, forward-looking households and credit-constrained households that consume their current income in each period (Bilbiie et al., 2008). This two-agent approach ensures both realistic short-term behavior in the model and that not all households can smooth consumption via access to financial markets, and thus are more immediately affected by shocks to the economy. The forward-looking households are described with an overlapping generations model inspired by Blanchard (1985). This ensures a flexible modeling of the model's long-term properties and better consistency with the Danish macro model MAKRO. GreenREFORM is calibrated to MAKRO in the baseline scenario to ensure consistency with the Ministry of Finance's medium- and long-term projections.

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GreenREFORM is a dynamic multi-sector CGE-model. The model can be seen as a further development of the static CGE model REFORM (Stephensen et al., 2019). In REFORM, a welfare measure is derived that can be decomposed into understandable individual components. This approach is also used here. The basic idea is the same as in Sørensen (2014), Goulder & Williams (2003), and Kleven & Kreiner (2006). Technically, marginal effects of changes in taxes and fees are calculated, and these marginal effects are broken down into individual components, which are sought to be explained and characterized. In GreenREFORM, a slightly different method is used, as the system is built to assess the welfare effects of absolute changes in taxes and fees (not marginal as in the mentioned theory papers). This is important in a model that is intended to be used to analyze large shocks.

The welfare objective used is a so-called Equivalent Variation measure (EV measure). The EV measure indicates, at a given shock to the economy, how many billion kroner households would need to receive in the base year to be indifferent to the shock. In this way, welfare effects are measured through many channels, such as price distortions and losses of various forms of income (wages, capital income, transfers, etc.). Any effects of the public sector's financing method can be analyzed (higher taxes, increased public debt, lower public consumption, etc.).

An element that distinguishes the welfare measure in GreenREFORM from many similar measures is the calculated effect of changes in stock prices. In GreenREFORM, industries are modeled as corporations that finance their investments through a combination of debt and self-financing. The value of the industry's share capital is measured as discounted future earnings. When the model is shocked, the stock price changes. In GreenREFORM, it is assumed that a share of the total share capital is owned by Danish households. The EV measure therefore measures the effect of these changes in stock prices on household welfare. This is a potentially important effect in a model that is built to calculate large shocks to the economy. If, for example, a tax almost closes down an industry, the capitalization effect of this will be measured in the welfare measure via this channel.

In section 2 the household is describet and in section 3 the welfare measure is derived.

2 Households

2.1 Forward-Looking Households

The households are described by an overlapping generations model as described in Blanchard (1985). Each individual household has a constant probability of death μ. When a death occurs, a child is born, so that the population remains constant. Let N_a be the number of households with initial age a. It then follows that:

$$N_a = \mu (1-\mu)^{a-1} N \tag{2.1}$$

such that

$$\sum_{a=1}^{\infty} N_a = N$$

In each period, μN households die and are born. We will initially assume that $N = 1$. Below, we generalize to the situation with a growing population.

Consider a household that at the end of period $t-1$ has age $a-1$. The expected future utility is given by:

$$U_{a-1,t-1} = \sum_{s=t}^{\infty} \frac{q_{a+s-t,s}^{1-\sigma}}{1-\sigma} \frac{B_s}{B_{t-1}} \frac{N_{a+s-t}}{N_{a-1}}, \tag{2.2}$$

where the discount factor is defined by

$$B_t = \prod_{s=0}^{t} \beta_s$$

and where the current utility $q_{a,t}$ for each household is given by

$$q_{a,t} = c_{a,t} - \phi \frac{l_t^{1+\eta}}{1+\eta}. \tag{2.3}$$

Here, $c_{a,t}$ is the consumption and l_t t is the hourly supply of labor.

The budget constraint for each household is given by

$$A_{a,t} = \frac{1+r_t}{1-\mu} A_{a-1,t-1} + y_t + (1-\tau_t) w_t l_t - P_t c_{a,t}, \tag{2.4}$$

where A_t is the household's wealth, $(1-\tau_t)w_t$ is the after-tax hourly wage, P_t is the consumer price index, r_t is the after-tax nominal interest rate, and y_t is 'other income' (e.g. transfer income). Note that we assume that y_t and $(1-\tau_t)w_t l_t$ are independent of age. Also note that, in addition to the nominal interest rate r_t, the household receives an actuarially fair "life annuity" with a gross rate of $1/(1-\mu)$ as long as it is alive.

Finally, we have a No-Ponzi condition:

$$\lim_{s\to\infty} A_{a+s-t,s} \frac{R_s}{R_{t-1}} = 0, \tag{2.5}$$

where the discount factor is defined by:

$$R_t \equiv \prod_{s=1}^{t} \frac{1-\mu}{1+r_s}.$$

2.1.1 Static Optimization

Let us first ensure that the budget constraint depends on the current utility $q_{a,t}$ instead of the current consumption $c_{a,t}$. We can rewrite (2.4) to:

$$A_{a,t} = \frac{1+r_t}{1-\mu} A_{a-1,t-1} + \hat{y}_t - P_t q_{a,t}, \tag{2.6}$$

where

$$\hat{y}_t \equiv y_t + (1-\tau_t)\, w_t l_t - P_t \phi \frac{l_t^{1+\eta}}{1+\eta}. \tag{2.7}$$

The variable $\hat{y}_t$ is called the *leisure-adjusted income*[1]. Notice that (2.7) is a static equation. If we wish to maximize utility (2.2) we should obviously maximize $\hat{y}_t$ in each period. This is done by choosing the optimal number of working hours in (2.7) in each period. This gives the labor supply function:

$$l_t = \left(\frac{1}{\phi} \frac{(1-\tau_t)\, w_t}{P_t} \right)^{\frac{1}{\eta}}. \tag{2.8}$$

The disutility of labor is given by:

$$z_t = \phi \frac{l_t^{1+\eta}}{1+\eta} = \frac{1}{1+\eta} \frac{(1-\tau_t)\, w_t}{P_t} l_t. \tag{2.9}$$

It can be seen that the disutility of labor is given by a share $1/(1+\eta)$ of the wage sum after tax. Substituting this into (2.7) yields:

$$\hat{y}_t \equiv y_t + (1-\tau_t)\, w_t l_t - z_t. \tag{2.10}$$

2.1.2 Dynamic optimization

We now have an optimization problem based on the utility function (2.2), the budget constraint (2.6), and the No-Ponzi-condition (2.5). We begin by transforming the utility function. This makes it easier to solve the dynamic problem and to define an EV measure. Define throughout the process

[1] We are working with disutility of labor instead of utility of leisure. However, it is more common to talk about the utility of leisure, and later we will be able to interpret our EV measure in this way

$s \geq t$:

$$\hat{U}_{a-1,t-1} = f\left(U_{a-1,t-1}\right) \equiv \left(\left(1-\sigma\right)U_{a-1,t-1}\right)^{\frac{1}{1-\sigma}}.$$

It holds that $f'\left(U_{a-1,t-1}\right) > 0$ for all σ, such that this is an allowed transformation of the utility function. [2].

It can be seen that $\hat{U}_{a-1,t-1}$ is a CES-function:

$$\hat{U}_{a-1,t-1} = \left[\sum_{s=t}^{\infty} \frac{B_s}{B_{t-1}} \frac{N_{a+s-t}}{N_{a-1}} q_{a+s-t,s}^{\frac{E-1}{E}}\right]^{\frac{E}{E-1}}, E = \frac{1}{\sigma}. \tag{2.11}$$

By solving the budget constraint (2.6) and applying the No-Ponzi condition (2.5) it can be shown that:

$$\sum_{s=t}^{\infty} P_s \frac{R_s}{R_{t-1}} q_{a+s-t,s} = A_{a-1,t-1} + H_{t-1}, \tag{2.12}$$

where

$$H_{t-1} \equiv \sum_{s=t}^{\infty} \hat{y}_s \frac{R_s}{R_{t-1}}. \tag{2.13}$$

We now have a classic CES-function (2.11) that needs to be maximized given a classic budget constraint (2.12). The optimal solution is:

$$q_{a+s-t,s} = \left(\frac{B_s}{B_{t-1}} \frac{N_{a+s-t}}{N_{a-1}}\right)^{E} \left(\frac{P_s \frac{R_s}{R_{t-1}}}{P_{t-1}^{U}}\right)^{-E} \frac{A_{a-1,t-1} + H_{t-1}}{P_{t-1}^{U}}, \tag{2.14}$$

where the CES-price index P_{t-1}^{U} is defined by:

$$P_{t-1}^{U} = \left[\sum_{s=t}^{\infty} \left(\frac{B_s}{B_{t-1}} \frac{N_{a+s-t}}{N_{a-1}}\right)^{E} \left(P_s \frac{R_s}{R_{t-1}}\right)^{1-E}\right]^{\frac{1}{1-E}}$$

or from (2.1):

$$P_{t-1}^{U} = \left[\sum_{s=t}^{\infty} \left(\frac{B_s}{B_{t-1}} \left(1-\mu\right)^{s-t+1}\right)^{E} \left(P_s \frac{R_s}{R_{t-1}}\right)^{1-E}\right]^{\frac{1}{1-E}}. \tag{2.15}$$

Note that one can derive the usual Keynes-Ramsey rule/Euler equation from (2.14):

$$q_{a+s+1-t,s+1} = \left(\frac{P_s}{P_{s+1}} \left(1 + r_{s+1}\right) \beta_{s+1}\right)^{E} q_{a+s-t,s}.$$

[2]For $q_s > 0$ it follows from (2.2) that $\left(1-\sigma\right)U_{t-1} > 0$ for all $\sigma \geq 0$. Therefore, it holds that $f'\left(U_{t-1}\right) = \left(\left(1-\sigma\right)U_{t-1}\right)^{\frac{\sigma}{1-\sigma}} > 0$ for $\sigma \geq 0$.

2.1.3 Aggregating

Consumption and wealth are distributed across ages. We wish to aggregate this. From (2.14) we have that:

$$q_{a,t} = \left(\frac{B_t}{B_{t-1}}\frac{N_a}{N_{a-1}}\right)^E \left(\frac{P_t \frac{R_t}{R_{t-1}}}{P_{t-1}^U}\right)^{-E} \frac{A_{a-1,t-1} + H_{t-1}}{P_{t-1}^U}$$

or

$$q_{a,t} = \left(\beta_t \left(1 + r_t\right) \frac{1}{P_t}\right)^E \frac{A_{a-1,t-1} + H_{t-1}}{\Omega_{t-1}}$$

where

$$\Omega_{t-1} \equiv \left(P_{t-1}^U\right)^{1-E} \tag{2.16}$$

We aggregate based on (2.1):

$$q_t \equiv \sum_{a=1}^{\infty} N_a q_{a,t} = \left(\beta_t \left(1 + r_t\right) \frac{1}{P_t}\right)^E \frac{\sum_{a=1}^{\infty} A_{a-1,t-1} N_a + H_{t-1}}{\Omega_{t-1}}$$

Since $A_{0,t} = 0$ (there is no inheritance in the model), it holds that

$$\sum_{a=1}^{\infty} A_{a-1,t-1} N_a = (1-\mu) \sum_{a=1}^{\infty} A_{a-1,t-1} N_{a-1} = (1-\mu) A_{t-1}$$

We therefore have that

$$q_t = \left(\beta_t \left(1 + r_t\right) \frac{1}{P_t}\right)^E \frac{(1-\mu) A_{t-1} + H_{t-1}}{\Omega_{t-1}} \tag{2.17}$$

We also aggregate the budget constraint. (2.6). By applying the same technique as above, we obtain:

$$A_t = (1 + r_t) A_{t-1} + \hat{y}_t - P_t q_t \tag{2.18}$$

The aggregated household can now be described by the equations (2.17) and (2.18). The variables H_t and Ω_t can be described as forward-looking equations from (2.13) and (2.15):

$$H_t = \frac{1-\mu}{1+r_{t+1}} \left(\hat{y}_{t+1} + H_{t+1}\right) \tag{2.19}$$

and

$$\Omega_t = \frac{1-\mu}{1+r_{t+1}} \left(\beta_{t+1} \left(1 + r_{t+1}\right)\right)^E \left(P_{t+1} + \Omega_{t+1}\right) \tag{2.20}$$

The modeling of the rational household is therefore given by the equations (2.17)-(2.20).

2.1.4 Population Development

In the above model, it is assumed that the population N is constant. GreenREFORM must be able to handle a situation with realistic future population development. We assume that changes in the population occur through net immigration of households that have the same wealth as the average domestic wealth and the same age distribution as domestic households. Under these assumptions, the representative household can still be described by (2.17), (2.18), (2.19), and (2.20). If M_t is the total population at time t, the total macroeconomic variables can be calculated as:

$$q_t^{\text{Tot}} = M_t q_t$$

$$A_t^{\text{Tot}} = M_t A_t$$

given that we have assumed above that $N = 1$.

2.1.5 Disaggregated Consumption

In GreenREFORM, households demand a wide range of goods. This occurs in a nested CES-demand system. Here, to demonstrate the principle, let us consider a simpler situation with only one nest and no imports. The demand for the j'th consumption good is given by:

$$c_{jt} = \mu_{jt}^C \left(\frac{\left(1 + \tau_{jt}^C\right) p_{jt}}{P} \right)^{-E^C} c_t. \tag{2.21}$$

Here, c_t is the aggregated consumption that is part of the utility function, and P is the consumer price index that is included in the budget constraint (2.4). τ_{jt}^C is a tax paid by consumers, and p_{jt} is the output price of firms.

The consumer price index P_t is defined by:

$$P_t c_t = \sum_j \left(1 + \tau_{jt}^C\right) p_{jt} c_{jt} \tag{2.22}$$

or alternatively

$$P_t = \left[\sum_j \mu_{jt}^C \left(\left(1 + \tau_{jt}^C\right) p_{jt} \right)^{1-E^C} \right]^{\frac{1}{1-E^C}}. \tag{2.23}$$

3 Welfare Measures

3.1 EV Measure for Forward-Looking Households

By substituting the solution (2.14) in (2.11) it can be seen that:

$$\hat{U}_{a-1,t-1} = \frac{A_{a-1,t-1} + H_{t-1}}{P^U_{t-1}} \tag{3.1}$$

If we aggregate with the initial population N_a, we obtain:

$$\hat{U}_{t-1} \equiv \sum_{a=1}^{\infty} \hat{U}_{a-1,t-1} N_a = \frac{(1-\mu)A_{t-1} + H_{t-1}}{P^U_{t-1}}$$

This is an important result, as it gives us an EV measure defined over a future path. Let us assume that for $s \geq t$ we have a baseline path that gives rise to the values $\left(A^0_{t-1}, H^0_{t-1}, P^{U0}_{t-1}\right)$. We now shock the model and obtain a new future path with values$\left(A_{t-1}, H_{t-1}, P^U_{t-1}\right)$. We now define the EV measure EV_{t-1} as the amount households must receive at the end of period $t-1$ to be indifferent between the two paths. It must hold that:

$$\frac{(1-\mu)A^0_{t-1} + H^0_{t-1} + EV_{t-1}}{P^{U0}_{t-1}} = \frac{(1-\mu)A_{t-1} + H_{t-1}}{P^U_{t-1}}$$

such that

$$EV_{t-1} = EV^P_{t-1} + EV^A_{t-1} + EV^H_{t-1}$$

where

$$EV^P_{t-1} \equiv \frac{P^{U0}_{t-1} - P^U_{t-1}}{P^U_{t-1}} \left((1-\mu)A_{t-1} + H_{t-1}\right)$$

$$EV^A_{t-1} \equiv (1-\mu)\left(A_{t-1} - A^0_{t-1}\right)$$

$$EV^H_{t-1} \equiv H_{t-1} - H^0_{t-1}$$

See the next section for an interpretation of this welfare measure.

Households that are born in the future are not included in the above welfare measure. A household born at the end of period $s \geq t$ will have the utility

$$\hat{U}_s = \frac{H_s}{P^U_s}$$

since it enters the economy without any wealth. If the EV measure is calculated as above, we obtain:

$$EV_s = EV_s^P + EV_s^H,\ s \geq t$$

where

$$EV_s^P \equiv \frac{P_s^{U0} - P_s^U}{P_s^U} H_s$$

$$EV_s^H \equiv H_s - H_{s-1}$$

The number of newborns will be μ (since we have assumed that $N = 1$). We therefore calculate the total EV measure as

$$EV_{t-1}^{\mu} = EV_{t-1} + \mu \sum_{s=t}^{\infty} EV_s \frac{S_s}{S_{t-1}} \tag{3.2}$$

where S_t is defined by:

$$S_t \equiv \prod_{s=1}^{t} \frac{1}{1+r_s}.$$

In (3.2) we have included households that are born from the current population, but we still need to account for any future growth in the population. The increase in population is assumed to arise from net immigration of individuals who are clones of current households. Therefore, the total EV measure can be calculated as

$$EV_{t-1}^{Total} = M_{t-1} \cdot EV_{t-1}^{\mu} + \sum_{s=t}^{\infty} (M_s - M_{s-1}) EV_s^{\mu} \frac{S_s}{S_{t-1}}$$

where M_{t-1} is the size of the population at the end of period $t-1$. If we assume that there is constant growth in the population:

$$M_t = (1+g) M_{t-1}$$

it holds that

$$EV_{t-1}^{Total} = M_{t-1} \cdot EV_{t-1}^{\mu} + \frac{g}{1+g} \sum_{s=t}^{\infty} M_s \cdot EV_s^{\mu} \frac{S_s}{S_{t-1}}$$

3.1.1 Interpretation of the Welfare Measure

The component EV_{t-1}^P measures the effect of future changes in prices. If a tax is imposed on a sector's goods, the deadweight loss will primarily be measured through EV_{t-1}^P (there will also be indirect effects through the other EV measures).

The size EV_{t-1}^H measures the effect of changes in future leisure-adjusted incomes. Here, the effects of changes in wage sums, transfer incomes, and leisure are measured. The way the government reacts to revenue changes will largely be measured through this EV measure. For example, distorting effects from changes in wage taxes will be measured here.

Finally, EV^A_{t-1} measures the effect of initial jumps in households' wealth. This is an element that is often overlooked in EV measures but can be potentially important. To the extent that households own domestic stocks, shocks to the economy will cause households' wealth to jump in a small open economy[3].

We can further break down EV^H_{t-1}:

$$EV^H_{t-1} = EV^y_{t-1} + EV^{wl}_{t-1} + EV^{\tau}_{t-1} + EV^z_{t-1} \tag{3.3}$$

where

$$EV^{wl}_{t-1} \equiv \sum_{s=t}^{\infty} \left(w_s l_s \frac{R_s}{R^0_s} - w^0_s l^0_s \right) \frac{R^0_s}{R^0_{t-1}}$$

$$EV^{\tau}_{t-1} \equiv \sum_{s=t}^{\infty} \left(\tau^0_s w^0_s l^0_s - \tau_s w_s l_s \frac{R_s}{R^0_s} \right) \frac{R^0_s}{R^0_{t-1}}$$

$$EV^{y}_{t-1} \equiv \sum_{s=t}^{\infty} \left(y_s \frac{R_s}{R^0_s} - y^0_s \right) \frac{R^0_s}{R^0_{t-1}}$$

$$EV^{z}_{t-1} \equiv \sum_{s=t}^{\infty} \left(z^0_s - z_s \frac{R_s}{R^0_s} \right) \frac{R^0_s}{R^0_{t-1}}$$

Here, EV^{wl}_{t-1} measures the utility effect of changed wage income, EV^{τ}_{t-1} measures the utility effect of changed wage tax, EV^y_{t-1} measures the utility effect of changed other income, and EV^z_{t-1} measures the utility effect of changes in leisure. If the nominal interest rate is not affected by the shock, it will hold that $R_s/R^0_s = 1$.

3.1.2 EV-effect of a Tax Change

Assume that at the end of period $t-1$ we decide to change a consumption tax τ^C_{js}, where $s \geq t$. In principle, we could assess the effect of a marginal change in τ^C_{js} by differentiating the price index (2.23) and then trace the effect throughout the model. This is how it is done in Sørensen (2014) and Goulder & Williams (2003). For example, we would be able to measure an effect on labor supply through the labor supply function (2.8). But such a direct effect on labor supply would lead to an indirect effect on the wage w_s, and if the public sector neutralizes the revenue effect through a change in the wage tax, there would also be an indirect effect on τ_s. Thus, we will have several different effects on EV^H_{t-1}. Changes in the wage sum will affect the wage sum EV EV^{wl}_{t-1} and the wage tax EV EV^{τ}_{t-1}. The change in wages will, through rate adjustments, affect transfer incomes and thus EV^y_{t-1}. The change in labor supply will impact the leisure-EV EV^z_{t-1}. Finally, it should

[3] In a closed economy, the interest rate will adjust.

be noted that the change will have indirect effects on the earnings of many economic sectors. This will affect the stocks of these sectors and thereby influence EV_{t-1}^{A}.

3.2 EV Measure of the Credit-Constrained Households

The households described above have perfect foresight and an infinite time horizon. It is known from the DSGE literature that the model's responses become more realistic in the short to medium term if a portion of the households is assumed to be credit-constrained (so-called hand-to-mouth households -hereafter referred to as H2M households), meaning households that spend all of their income each period. By having a portion of H2M households, one can control the model's short-term marginal propensity to consume. This also affects the model's welfare effects, as we now have a portion of households that cannot smooth consumption through financial markets and are therefore more directly impacted by shocks to the model.

Each H2M household is assumed to maximize its utility function in each period:

$$q_t^{H2M} = c_t^{H2M} - \phi \frac{\left(l_t^{H2M}\right)^{1+\eta}}{1+\eta},$$

under the budget constraint

$$P_t c_t^{H2M} = y_t^{H2M} + (1-\tau_t)\, w_t l_t^{H2M}.$$

We assume that the H2M households have the same nest structure as the rational households, such that P_t is the same consumer price index. Following the same approach as above, the budget constraint is rewritten as

$$P_t q_t^{H2M} = \hat{y}_t^{H2M} \tag{3.4}$$

where the leisure-adjusted income is given by:

$$\hat{y}^{H2M} = y_t^{H2M} + (1-\tau_t)\, w_t l_t^{H2M} - P_t \phi \frac{\left(l_t^{H2M}\right)^{1+\eta}}{1+\eta}$$

As with the rational household, the optimal labor supply is given by:

$$l_t^{H2M} = \left(\frac{1}{\phi} \frac{(1-\tau_t)\, w_t}{P_t}\right)^{\frac{1}{\eta}}$$

The disutility of labor is given by

$$z_t^{H2M} = \phi \frac{\left(l_t^{H2M}\right)^{1+\eta}}{1+\eta} = \frac{1}{1+\eta} \frac{(1-\tau_t)\, w_t}{P_t} l_t^{H2M}$$

and it holds that

$$\hat{y}_t^{H2M} \equiv y_t^{H2M} + (1-\tau_t)\, w_t l_t^{H2M} - z_t^{H2M}$$

3.2.1 EV Measure for Credit-Constrained Households

From (3.4) it can be seen that:

$$q_t^{H2M} = \frac{\hat{y}_t^{H2M}}{P_t}$$

Let us assume that for $s \geq t$, we have a baseline scenario that gives rise to the values $\left(\hat{y}_s^{H2M0}, P_s^0\right)_{s\geq t}$. We now shock the model and obtain a new future scenario with values $\left(\hat{y}_s^{H2M}, P_s\right)_{s\geq t}$. We now define the EV measure ev_s^{H2M} as the amount households must receive in period s to be indifferent between the two scenarios. It must hold that:

$$\frac{\hat{y}_s^{H2M0} + ev_s^{H2M}}{P_s^0} = \frac{\hat{y}_t^{H2M}}{P_t}$$

such that

$$\begin{aligned} ev_s^{H2M} &= \frac{P_s^0 - P_s}{P_s} \hat{y}_t^{H2M} + \left(\hat{y}_t^{H2M} - \hat{y}_t^{H2M0}\right) \\ &\equiv ev_s^{H2M,P} + ev_s^{H2M,H} \end{aligned}$$

We now choose to discount these EV measures back, so that we obtain a total EV measure that can be added to the EV measures of the rational households:

$$EV_{t-1}^{H2M} = \sum_{s=t}^{\infty} ev_s^{H2M} \frac{S_s^0}{S_{t-1}^0}$$

$$EV_{t-1}^{H2M,P} = \sum_{s=t}^{\infty} ev_s^{H2M,P} \frac{S_s^0}{S_{t-1}^0}$$

$$EV_{t-1}^{H2M,H} = \sum_{s=t}^{\infty} ev_s^{H2M,H} \frac{S_s^0}{S_{t-1}^0}$$

where

$$S_t \equiv \prod_{s=1}^{t} \frac{1}{1+r_s}.$$

The decomposition of EV^{H}_{t-1} (3.3) can also be applied to $EV^{H2M,H}_{t-1}$.

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