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Optimal Social Insurance:
Insights from a Continuous-Time Stochastic Setup

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Abstract
This paper focuses on the determinants of the optimal level of social insurance, thus contributing to explain its cross-country variation. In a continuous-time stochastic endogenous growth setup, it is a form of public insurance against idiosyncratic shocks affecting the income, as well as the dependency ratio of an individual household. Such shocks include, for example, illness, disability, unemployment, or changes in the number of infants and elderly in care. We conclude that a higher average dependency ratio and a higher covariance between technological and dependency shocks both decrease the optimal amount of social insurance. In addition, a higher variance of technological shocks does not affect optimal decisions, while a higher variance of dependency shocks increases optimal social insurance, provided the covariance between technological and dependency shocks is not very negative.

JEL: H55, C61

Keywords: Social insurance; Dependency; Technological shocks; Continuous-time stochastic methods.

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". . . those who are disabled from work by age and invalidity
have a well-grounded claim to care from the State."
Germany's Emperor, William the First

1. Introduction

In virtually every country of the world, there is some form of social insurance. Such an arrangement aims to financially support families whose members are either too old or too young to work, are temporarily or permanently out of work due to illness, disability or unemployment, or simply had the misfortune of becoming orphaned or widowed. Indeed, to different degrees in different countries, insurance against such idiosyncratic shocks is provided by combining intra-family ties with formal tax and transfer systems. In historical terms, only in the late 19th century did the State became a provider of social insurance and, mostly so, in advanced economies. The argument for public social insurance is that some types of shocks cannot be insured at the household level, but only collectively. It is in this context that we proceed to determine the optimal level of social insurance, taking into account not only preferences, the average dependency ratio, and the average rate of return on capital, but also, crucially, the size, variance and covariance of dependency as well as technological shocks.

In this paper we determine the optimal choice for social insurance in an economy with an infinitely-lived individual household that operates in a continuous-time stochastic setup. With logarithmic preferences, a closed-form solution is obtained. In this stylized setting, there is a publicly-provided insurance against dependency shocks, which can be interpreted as spells of unemployment, illness, or disability, as well as changes in the number of infants or elders in care. This individual household decides how much to consume and how much to invest in each instant. It also allocates resources to an asset that, despite its negative expected return, offers a payment when the household is adversely affected by a negative dependency shock. This asset mimics the social insurance component of a public tax and transfer system, in that it provides (net positive) payments to the household when dependency ratios exceed expected values, and brings in contributions, otherwise. The expected rate of return on this asset is negative, only because of the administrative costs paid by the household. Overall, this asset works as an insurance against dependency shocks.

There is an extensive literature on the link between insurance, pensions and social security. Important contributions are Bodie (1990), Merton *et al.* (1987), Diamond and Mirrlees (1985), Fields and Mitchell (1984), and Kotlikoff and Spivak (1981). However, the literature on the underlying determinants of social insurance is relatively slim. Some contributions are Mina (2018) that focuses on the role of labor market flexibility using data on 55 developed and developing countries, and Gioacchino *et al.* (2014) that models the choice for social protection as an alternative to regulation in cushioning shocks. As far as we know, there is still no contribution that explicitly views and models social protection as a public insurance against technological and dependency shocks. Nevertheless, continuous-time stochastic models similar to ours have been widely used in the literature, notably to define optimal portfolios (e.g. Malliaris and Brock (1982)). In this paper we follow the optimization approach presented in Turnovsky (1995).

In our highly stylized setup, with logarithmic preferences, we find that the desired amount of social insurance decreases both with the average dependency ratio and with the covariance between technological and dependency shocks. Moreover, optimal social insurance increases with the variance of dependency shocks, provided the covariance between technological and dependency shocks is not very negative.

The paper is organized as follows. In order to frame the analysis, the next section presents basic indicators on social protection for a set of advanced economies. In section 3, we present the problem of the individual household that, in each instant, optimally allocates existing resources to social insurance, to consumption and to capital accumulation. In section 4, we derive the solution to the continuous-time stochastic setup. Section 5 presents closed-form solution results under logarithmic preferences. In section 6, an illustration based on a range of parameters is used to assess our results in a broader setting. Section 7 offers some concluding remarks.

2. Social protection

The size of public social protection[1] systems in advanced economies varies markedly. Figure 1 presents overall social protection spending, as a percentage of GDP, broken down into its public and private components, for a set of OECD countries in 2013. In this sample, total social expenditure ranges from a minimum of 7.7 per cent of GDP in Mexico, to a maximum of 34.9 per cent in France, with the OECD average close to 24 per cent. Of the total, the public part dominates, except in the case of the US and, to a lesser extent, in Iceland, Sweden, Switzerland, Canada and the UK. Social protection spending comprises very different components, including not only old-age pensions, but also disability payments, health support and unemployment subsidies. Some of these components can be easily provided through private insurers, while others require State intervention. Overall, beyond equity considerations, the public provision of social protection by the State improves risk sharing because the pool of agents involved is unquestionably larger.

1. Social protection and social insurance are not synonyms. While social insurance is mostly concerned with managing risk and volatility to income security over one's lifecycle, social protection goes beyond the latter to include, for example, active labor market programs, housing allowances, and other social policy benefits aimed at reducing poverty, vulnerability and social exclusion.

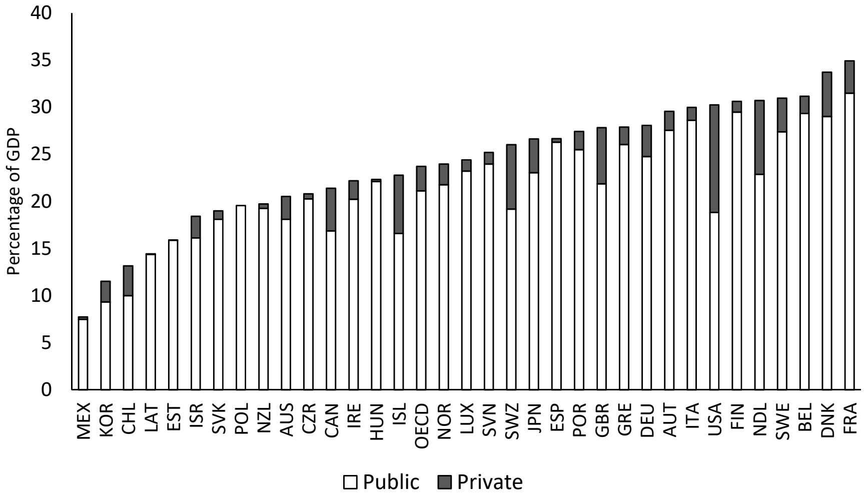


Figure 1: Social protection spending as a percentage of GDP

Source: OECD Social expenditure database. Note: Data for 2013. Values comprise old age, survivors, incapacity-related benefits, health, family, active labor market programmes, unemployment, housing, and other social policy areas.

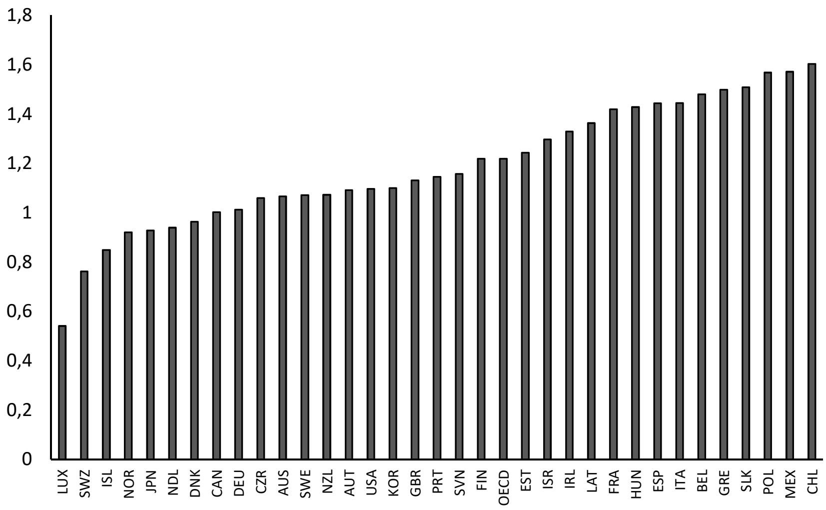


Figure 2: Dependency ratio

Source: OECD. Note: Average over 1995-2017. Dependency ratio is defined as the number of inactive elements in the household as a percentage of those who are active, proxied by (Total population-Employment)/Employment.

A key feature of our setup is the dependency ratio, measured by the number of inactive elements per household, as a percentage of those who are active. Figure 2 reports on the dependency ratio from an aggregate perspective, thus calculated for a set of OECD countries over 1995-2017. A cursory analysis reveals quite stark differences, with the dependency ratio ranging from 0.5 and 0.8 in Luxembourg and Switzerland, respectively, to 1.6 in Mexico and Chile. Over time, these ratios are quite stable, as is usually the case for demographic variables. However, it is very important to highlight that, for the individual household, the variance of these shocks is much larger than the corresponding number for the aggregate, where individual shocks tend to cancel out.

3. The setup: the individual household and the flow constraint

Assuming constant relative risk aversion (CRRA) preferences with $\gamma \leq 1$ and $\gamma \neq 0$, the individual household, comprised of infants, retirees and working-age individuals, some of whom in any instant can be sick and or disabled, maximizes an infinite sum of consumption flows, C, intertemporally discounted at rate β:

$$\int_{t=0}^{\infty} \frac{C^{\gamma}}{\gamma} e^{-\beta t} dt \tag{1}$$

The proportion of dependent household elements, relative to those who are active is defined as the dependency ratio (N), and follows a stochastic process with a deterministic component n and an idiosyncratic stochastic shock $d\theta$, that is assumed intertemporally independent and normally distributed with zero mean and variance σ_{θ}^2. That is:

$$dN = ndt + d\theta \tag{2}$$

Furthermore, we assume a stochastic AK-type technology:

$$dY = \alpha K dt + \alpha K dy \tag{3}$$

where K is the individual household's capital stock, and α is a technological parameter. In addition, there is a pure technological shock, dy, an intertemporally independent, normally distributed stochastic process with zero mean and variance σ_y^2.

As mentioned before, the individual household chooses the optimal amount of the available asset as a way of insuring against adverse dependency shocks. The expected return on each unit of insurance (S) is zero, but in every instant, it pays an amount that corresponds to the dependency shock that hits the household ($d\theta$). In addition, all costs associated with the management of this public insurance scheme are assumed to be proportional to its size, up to parameter φ. This stylized setup captures the budgetary operation of an intertemporally-balanced social insurance system that offers protection against dependency shocks.

Total capital stock of the household is K, and it is the state variable in our continuous-time stochastic optimization problem. It evolves according to the following flow constraint:

$$\frac{dK}{K} = \frac{\alpha K}{K}(dt + dy) - \frac{C}{K}(1+n)dt - \frac{C}{K}d\theta - \varphi\frac{S}{K}dt + \frac{S}{K}d\theta \tag{4}$$

where there are two sources of uncertainty, $d\theta$ and dy, with covariance $\sigma_{y\theta}$.

A key assumption of the previous equation is that the consumption of active and inactive members of the household is equal. In addition, we do not consider any impact of the dependency ratio on the rate of return on capital. Therefore, the flow constraint is a stochastic process with deterministic and stochastic components that can de defined as $\frac{dK}{K} = \eta dt + dk$,respectively, where:

$$\eta = \alpha - \frac{C}{K}(1+n) - \varphi\frac{S}{K} \tag{5}$$

$$dk = \alpha dy - \frac{C}{K}d\theta + \frac{S}{K}d\theta \tag{6}$$

4. Solution

Taking the stochastic flow constraint presented in the previous section, we can derive the variance of the state variable, K. This variance is labeled as σ_K^2 and is given by:

$$\sigma_K^2 = E(dK)^2 = \alpha^2\sigma_y^2 + \left(n_S - \frac{C}{K}\right)^2\sigma_\theta^2 + 2\alpha\left(n_S - \frac{C}{K}\right)\sigma_{y\theta} \tag{7}$$

where, for simplicity, we write n_S as the ratio of insurance, S, to the capital stock, K.

The derivatives of the variance of capital, relative to the two control variables in the model, n_S and $\frac{C}{K}$, are respectively:

$$\frac{\partial\sigma_K^2}{\partial n_S} = 2\left(n_S - \frac{C}{K}\right)\sigma_\theta^2 + 2\alpha\sigma_{y\theta} \tag{8}$$

$$\frac{\partial\sigma_K^2}{\partial\frac{C}{K}} = -2\left(n_S - \frac{C}{K}\right)\sigma_\theta^2 - 2\alpha\sigma_{y\theta} \tag{9}$$

The solution to the stochastic optimization problem is based on Malliaris and Brock (1982) and Turnovsky (1995). Given the structure of our setup, we can derive a closed-form solution for the control variables. The stochastic Lagrangian function of the problem is:

$$\begin{aligned} L = {} & \frac{1}{\gamma}\left(\frac{C}{K}\right)^\gamma K^\gamma e^{-\beta t} + \frac{\partial V(K,t)}{\partial t} + \\ & \left(\alpha - \frac{C}{K}(1+n) - \varphi n_S\right)K\frac{\partial V(K,t)}{\partial K}e^{-\beta t} + \frac{1}{2}\sigma_K^2 K^2\frac{\partial^2 V(K,t)}{\partial K^2}e^{-\beta t} \end{aligned} \tag{10}$$

where $V(K,t)$ stands for the value function of the problem. The value function is assumed time dependent, only accounting for the effect of discounting, that is $V(K,t) = e^{-\beta t}X(K)$. In addition, given the homogeneity conditions in this problem, the suggested value function is of the type, $X(K) = \delta K^{\gamma}$ and the parameter δ is not necessary for the solution.

The first-order conditions of the problem with respect to $\frac{C}{K}$ and n_S are, respectively:

$$\left(\frac{C}{K}\right)^{\gamma-1} K^{\gamma} - (1+n)\,\delta\gamma K^{\gamma} + \left[-\left(n_S - \frac{C}{K}\right)\sigma_{\theta}^2 - \alpha\sigma_{y\theta}\right]\delta(\gamma-1)\gamma K^{\gamma} = 0 \quad (11)$$

$$-(1+\varphi)\delta\gamma K^{\gamma} + \left[\left(n_S - \frac{C}{K}\right)\sigma_{\theta}^2 + \alpha\sigma_{y\theta}\right]\delta(\gamma-1)\gamma K^{\gamma} = 0 \quad (12)$$

while the Bellman equation is written as:

$$\frac{K^{\gamma}}{\gamma}\left(\frac{C}{K}\right)^{\gamma} - \beta\delta K^{\gamma} + \left(\alpha - \frac{C}{K}(1+n) - \varphi n_S\right)\delta\gamma K^{\gamma} - \frac{1}{2}\sigma_K^2\delta(\gamma-1)\gamma K^{\gamma} = 0 \quad (13)$$

Therefore, substituting equation (11) into (13), and simplifying, we have:

$$\frac{C}{K}\left[(1+n) - \left[\left(n_S - \frac{C}{K}\right)\sigma_{\theta}^2 - \alpha\sigma_{y\theta}\right](\gamma-1)\right] - \beta + \left(\alpha - \frac{C}{K}(1+n) - (1+\varphi)n_S\right)\gamma + \frac{1}{2}\left(\alpha^2\sigma_y^2 + \left(n_S - \frac{C}{K}\right)^2\sigma_{\theta}^2 + 2\alpha\left(n_S - \frac{C}{K}\right)\sigma_{y\theta}\right)(\gamma-1)\gamma = 0 \quad (14)$$

Finally, a transversality condition must be verified. It states that, when $t \to \infty$, the expected discounted value of the capital stock is zero, i.e., $\lim_{t\to\infty} E[Ke^{-\beta t}] = 0$. We analyze this condition in Appendix A.

5. The case of logarithmic preferences

Equations (11) and (12) fully determine the solution to the stochastic optimization problem. The nonlinear system of equations can be calibrated and solved for the purpose of simulation exercises. Nevertheless, if we revert to the case of logarithmic preferences, which is equivalent to assuming $\gamma = 0$, the solution is simple to analyze.

Under this hypothesis, we obtain:

$$\frac{C}{K} = \frac{\beta}{1+n+\varphi} \tag{15}$$

$$n_S = \frac{\beta}{1+n+\varphi} - \frac{\alpha\sigma_{y\theta}+\varphi}{\sigma_\theta^2} \tag{16}$$

As would be expected, if the covariance between dependency and technological shocks is zero ($\sigma_{y\theta} = 0$), and if there are no administrative costs associated with the provision of social protection ($\varphi = 0$), then the optimal n_S is such that the uncertainty arising from dependency is fully eliminated (full insurance is thus optimal, with $n_S = \frac{C}{K}$).

The impact on the optimal choice of social insurance of changes in the average dependency ratio, in the variance of dependency shocks, and in the covariance between the latter and technological ones is given by the following three partial derivatives, respectively:

$$\frac{\partial n_S}{\partial n} = \frac{\partial \frac{C}{K}}{\partial n} = -\frac{\beta}{(1+n+\varphi)^2} < 0 \tag{17}$$

$$\frac{\partial n_S}{\partial \sigma_\theta^2} = \frac{\alpha\sigma_{y\theta}+\varphi}{(\sigma_\theta^2)^2} \tag{18}$$

$$\frac{\partial n_S}{\partial \sigma_{y\theta}} = -\frac{\alpha}{\sigma_\theta^2} < 0 \tag{19}$$

There is a close link between the optimal level of consumption for each member of the household and the optimal amount of social insurance. An increase in the average dependency ratio leads to a lower optimal consumption for each member of the household, and thus also to a decrease in the desired amount of social insurance. An increase in the average dependency ratio increases the opportunity cost of consumption, relative to that of capital accumulation. In addition, if the covariance between dependency and technological shocks is positive, a larger variance of the former type of shocks increases the optimal amount of social insurance. As expected, under risk aversion, higher uncertainty leads to more insurance being desired. However, if the covariance between dependency and technological shocks is sufficiently negative, it becomes optimal to have less social insurance. That only occurs in a scenario where the optimal size of the social insurance exceeds the optimal level of consumption for each member of the household, a case that should lie outside a realistic range of parameters. Finally, the higher the covariance between technological and dependency shocks, the lower the optimal amount of social insurance. In this case, higher dependency ratios would materialize more frequently at times where the return on capital is also higher, thus effectively reducing the benefits of social insurance.

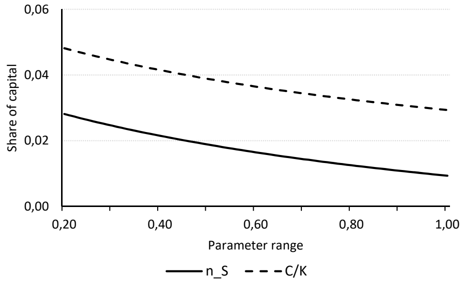
6. An illustration based on ranges for parameters

In this section, we parameterize our setup and plot the changes in the optimal levels of the control variables, C/K and n_S, around an illustrative benchmark scenario. The type of household data necessary for a more realistic setting of the key parameters is not readily available. Therefore, the objective of the exercise is not to approximate stylized facts or to replicate the case of a specific country (or set of countries), but simply to analyze the impact of changes in the parameters when the utility function is of the CRRA form, but not restricted to the logarithmic case. The setting of parameters is such that the control variables stay within a range of realistic values.

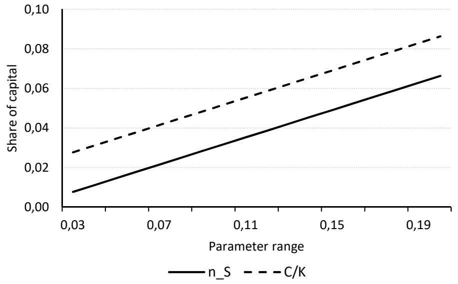
Parameter	Description	Value
n	Average dependency ratio	0.4
α	Average rate of return on capital	0.05
β	Intertemporal discount rate	0.07
γ	1 - Coefficient of relative risk aversion	-1
φ	Administrative costs parameter	0.05
σ_y^2	Variance of technological shocks	0.03
σ_θ^2	Variance of dependency shocks	1
$\sigma_{y\theta}$	Covariance between technological and dependency shocks	-0.1

Table 1. Baseline illustration

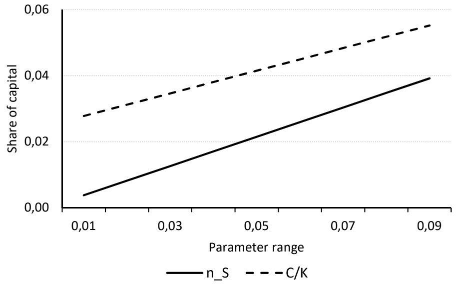
Figure 3 plots the effect on the two control variables of our setup of changes around the illustrative baseline of Table 1 for each parameter separately. The main results do not deviate markedly from those obtained in the case of logarithmic preferences. The optimal amount of social insurance, n_S, is negatively related to average dependency, to the covariance between dependency and technological shocks, to administrative costs, and to the rate of return on capital.



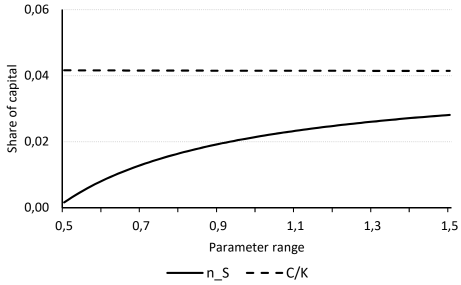
(a) Average dependency ratio (n)



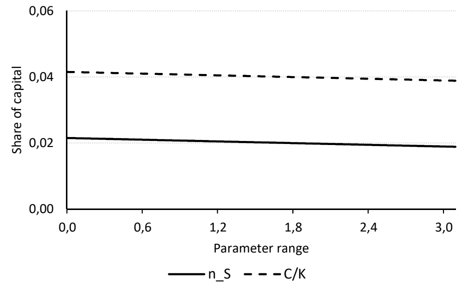
(b) Intertemporal discount rate (β)



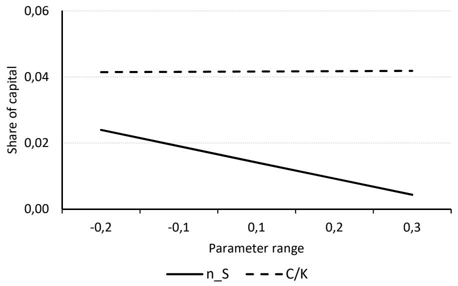
(c) Average rate of return on capital (α)



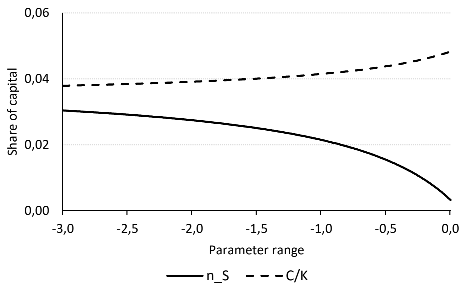
(d) Variance of the dependency shock (σ_θ^2)



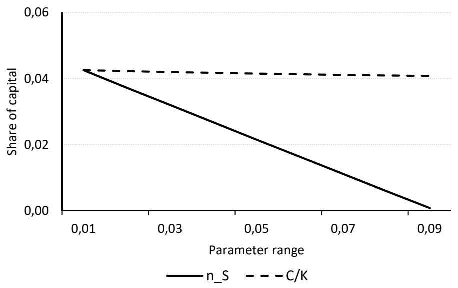
(e) Variance of the technological shock (σ_y^2)



(f) Covariance between the two shocks ($\sigma_{y\theta}$)



(g) 1 - Coefficient of relative risk aversion (γ)



(h) Administrative costs (φ)

Figure 3: Simulation - Changes around the baseline parameters

Note: The values of the endogenous variables (n_S and C/K) are computed based on the illustrative baseline in Table 1 for a range of values of the variable of interest on the horizontal axis.

7. Concluding remarks

As a significant component of social protection, social insurance is a key feature in the organization of all contemporary economies and societies. Despite this ubiquity, understanding cross-country differences that persist is still mostly a complex and incomplete endeavor. In this paper, we offer a stylized setup with insights into what determines optimal social insurance. We find that the desired amount is strongly linked to the level of consumption of each member of the household. Furthermore, along with the average dependency ratio, the variance and covariance between shocks in the economy play a crucial role.

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Appendix: Transversality condition

The optimal solution to the continuous-time stochastic problem, defined by equations (11) and (12), must satisfy the transversality condition, which for the constant elasticity utility function is:

$$\lim_{t\to\infty} E[Ke^{-\beta t}] = 0 \tag{A.1}$$

The equation that describes the accumulation of the capital stock of the individual household can be written as $dK = \psi K dt + K dk$, where $\psi = \alpha - \frac{C}{K}(1+n) - \varphi n_S$ and $dk = \alpha dy - \frac{C}{K}d\theta + n_S d\theta$. Starting from the initial capital stock at time 0 we write:

$$K(t) = K(0)e^{(\psi-(1/2)\sigma_k^2)t} + k(t) - k(0) \tag{A.2}$$

The transversality condition A.1 is met if and only if $\gamma(\psi - (1/2)\sigma_k^2) - \beta < 0$. This condition is automatically met for the logarithmic utility function ($\gamma = 0$). In other cases, this condition may impose restrictions on the parameters for the solution to be feasible. These restrictions are respected in the simulation presented in Figure 3.

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