Dynamic of the Disablement Process in Ageing Populations

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Abstract – This paper aims at projecting the disabled population aged 60 or more, and at identifying the factors that impact those projections. To this aim, we develop a novel methodological approach which allows identifying the role of different parameters (e.g. a change in the probability to remain autonomous, a change in the distribution of survival gains across disability levels) in the forecast of morbidity. This paper focuses on the methodological aspect of this new method. It also provides, as an illustration, a projection of the French elderly disabled population in 2060, relying on the French CARE‑M data and on the European data SHARE. It shows that matching the past evolution of the disability‑free life expectancy ratio to the total life expectancy requires optimistic assumptions regarding the evolution of the probability to remain autonomous.

JEL: J14, I19, Z18
Keywords: Microsimulation, ageing, elderly disability, long-term care

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In the last decade, most developed countries have experienced an increasing demand for long-term care provision. With increased life expectancy, and ageing baby boom cohorts, many policy experts fear a steep rise in care needs of disabled elderly. By 2050, 10% of the population of OECD countries is expected to be over the age of 80, against 4% in 2010 (Colombo *et al.*, 2011). This has prompted researchers to develop models to quantify the extent of the additional care needs. In the US, the Dynamic Simulation of Income Model (DYNASIM, Johnson *et al.*, 2007; Favreault *et al.*, 2015) was the first large-scale dynamic microsimulation model; the later version of the model then allowed modelling individuals' health status. The evolution of the need for informal or formal care is now projected through microsimulation models in Canada (Lifepaths, POHEM models, Hennessy *et al.*, 2015), Spain (DemoCare, Spijker *et al.*, 2022) or in the UK (PacSim, Wittenberg *et al.*, 2020), for instance. The underlying key question was which scenario might prevail between a possible compression or expansion of morbidity, i.e. how the decline in the mortality rate would translate into more or less years of healthy life.

These previous studies can be categorized along two main strands. First, projections inspired by pension projections: they mostly rely on administrative measures of health and depend on socio-economics factors rather than on health characteristics. In these approaches, long-term care needs are bypassed by measures of care use, or by administrative eligibility criteria to current long-term care provision (see Rutter *et al.*, 2011, Schofield *et al.*, 2018 for surveys; Bontout *et al.*, 2002; Duée & Rebillard, 2006; Lecroart *et al.*, 2013; Marbot & Roy, 2015 for studies on French data; Hancock *et al.*, 2005 for the UK; Fukawa, 2012 for Japan). The main limitation of such modelling is that it remains independent from underlying health changes, sensitive to non-take-up rate and highly influenced by current care provision. Moreover, the use of administrative measures of health makes the results hardly comparable between countries and subject to changes in the disability definition across time. To understand whether developed countries now face a "long-term care time bomb" or not, one must study thoroughly the ageing process underlying the change in long-term care needs. The second strand of the literature uses dynamic microsimulation models, and relies on an epidemiological approach to disability status. Those studies rely on survey data providing information on limitations in Activities of Daily Living (ADL) and Instrumental Activities of Daily Living (IADL). ADLs refer to people's daily self-care activities while IADL do not include ADL and refer to activities that are not necessary for fundamental functioning but necessary to let an individual to live independently in a community. This typology makes the distinction between activities implying taking care of the body from those which are not essential but allow living autonomously. The advantage of the use of epidemiological measures, rather than administrative ones, is to include individuals who are disabled but do not seek any allowance. The prevalence of different levels of disability is projected using models which take as inputs the trends of underlying diseases leading to different disability levels. For example, Kingston *et al.* (2018b) project the prevalence of several diseases in the UK using the PacSim model. Ahmadi-Abhari *et al.* (2017) provide a forecast of the prevalence of dementia in the UK using IMPACT-BAM model (see Norton *et al.*, 2013 for a review of previous microsimulation models on dementia). Légaré *et al.* (2014) project the disability status of the Canadian population, using LifePaths, or more recently the POHEM model from Statistics Canada. While this approach uses detailed measures of health status and underlying health conditions, mortality remains projected separately – using official mortality projections – and changes in health conditions are not taken into account in the conditional death rates. Life expectancy gains are thus distributed homogeneously to all health states (including autonomy and light to severe disability). This is an important assumption, as elderly disability projections largely depend on the source of life expectancy gains within each health status. To our knowledge, the American FEM model (Leaf *et al.*, 2020), estimated using the Health and Retirement Study data, is the only one allowing mortality to be partly determined by disability. In this model, mortality depends on age, race/ethnicity, gender, education, smoking, chronic health conditions, and limitations in IADL and ADL.

This article relates to this second strand of approaches. We propose a microsimulation model to forecast disability in the elderly population, with a novel methodological approach allowing to identify the role of different parameters in the morbidity forecast. We focus on the dynamics of the process of disablement at older ages, i.e. the flow onto disability states rather than the stock of elderly disabled individuals. Our approach relies on theoretical scenarios regarding the evolution of the transitions between states. Thus, our approach is complementary to that of Leaf *et al.* (2020), who rely on the projected evolution of some diseases to forecast the evolution of mortality.

The first section of the article presents the main steps of our methodological approach: estimating the transition rates between disability states, building scenarios and projecting elderly disability. A central feature of our microsimulation model is that it allows several options (and corresponding parameters) to allocate mortality decreases and to adjust the transitions between disability states depending on the considered scenarios, hence allowing identifying the effect of a parameter in a projection. The second section provides an illustration of its application, with a projection of the French elderly disabled population in 2060 under a few scenarios. We rely on the projections of the French National Institute of Statistics and Economic Studies (INSEE) for mortality, on the CARE-M survey, a French cross-section survey of elderly population, to measure the prevalence of disability, and on the European Survey of Health, Ageing and Retirement in Europe (SHARE) to estimate the probabilities of transition between health states. The projection is carried out in four scenarios which correspond to different ways to allocate survival gains across disability states. We also consider the effect of an increased probability of remaining autonomous. Our baseline scenario relies on a standard hypothesis regarding the life expectancy evolution in France, and on assumptions regarding life expectancy gains which are similar to those made in previous studies (Lecroart *et al.*, 2013; Marbot & Roy, 2015; Roussel, 2017). We show that those assumptions are pessimistic, regarding the evolution of disability-free life expectancy gains, and lead to projections that go against the evolution of the disability-free to total life expectancy ratio observed in the past. On the other hand, we highlight that matching the past evolution of this ratio requires an optimistic assumption regarding the evolution of the probability to remain autonomous.

1. Microsimulation of the Disablement Process

The point of departure of the microsimulation is the distribution of the population of interest (here the population aged 60 and over) by disability states. Then, the method relies on the following steps:

1. We estimate transition probabilities from one state to another (Section 1.1)
2. We use external projections to estimate death probabilities by age and gender (Section 1.2)
3. We decide how to split death probability decreases between disability states (Section 1.3)
4. We adjust transitions to other states than death (Section 1.4)
5. We choose how to attribute disability states to new elderly, the 60 years old (Section 1.5)

We present alternative choices for these steps, to obtain different scenarios about the evolution of the elderly population.

We define five disability states relying on the epidemiological definition of Barberger-Gateau *et al.* (2000) and Pérès *et al.* (2005). It provides a more flexible tool for disability projection than an administrative measure, which relies on being recipient for disability allowances.

The study of disablement process requires making a trade-off between the statistical precision of the estimation and the ability to describe the population trajectories. Moreover, it requires building a disability scale, based on epidemiological evidence that the scale is relevant from the point of view of the aging process and loss of autonomy process. Most studies consider various combinations of functional limitations, IADL and ADL limitations, but there is no gold standard for the measure of the disability process, and the scale chosen varies from one study to another. Here, we choose to follow Pérès *et al.* (2005), whose scale reflects a progressive loss of autonomy. Thus, we consider a total of 4 disability states plus a last state being death: State 0 (autonomy) consists in having no limitation; State 1 (low disability) is having at least one Rosow's functional limitation (Rosow & Breslau, 1966); State 2 (medium disability) is having at least one functional limitation and one IADL limitation (Lawton & Brody, 1969); and State 3 (high disability) is having at least one functional limitation, one IADL limitation and one ADL limitation (Katz *et al.*, 1970). State 4 is death.[1]

The Rosow functional limitations (Rosow & Breslau, 1966) include difficulties with: walking 100 meters, climbing one flight of stairs and lifting or carrying weight over 5 kilos. Instrumental activity daily living (IADL) limitations (Lawton & Brody, 1969) include: difficulties with phone call, shopping, taking medications and managing money. For women, it also includes preparing hot meal and doing work around the house. Activity daily living (ADL) limitations (Katz *et al.*, 1970) include difficulties with: bathing or showering, dressing, using the toilet, getting in or out of bed, eating, cutting up food. We sum up possible transitions between those different states in Figure I.

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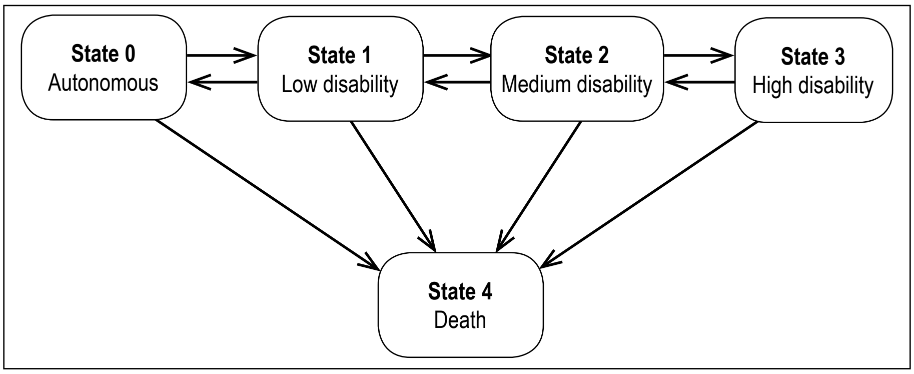
[1] *More details on the definition of disability states in this article and in previous studies are in Appendix.*

Figure I – **Transitions between disability states and death**



1.1. Transition Probabilities Between Disability States and Death

We consider that, in each state i (0 to 3), an individual has a non-zero probability to die (i=4). We also allow for transitions in both directions, reflecting that remissions can occur. However we only authorize transitions from one state to the closest other, or to death: for example an individual in state 1 can only switch to state 0, to state 2, or to death (cf. Figure I).

We estimate the probability that an individual switches from one disability state i in $t-1$ to another state j in t, conditionally to his/her disability state in $t-1$ and observed characteristics X. Such a Markovian process is estimated through a multinomial logit model[2] (Equation 1).

$$\frac{P(Y_t = j \mid X_{t-1},\ Y_{t-1} = i)}{P(Y_t = k \mid X_{t-1},\ Y_{t-1} = i)} = \exp(X'_{t-1}\kappa_{ij}) \qquad (1)$$

with Y_t the state observed in t, I in {0, 1, 2, 3}, j and k in {0, 1, 2, 3, 4}and k different from j. κ_{ij} is the conditional probability to switch from one state i to state j. Individual characteristics, denoted by X_t are age and gender. Note that the subsequent disability projection might be improved by adding control variables.

The estimated marginal effects at the mean can be presented as follows. For each age a and gender g, the $P\,|_{a,g}$ matrix describes the probability to switch from state i to state j, such that:

$$P\,|_{a,g} = \begin{pmatrix} P_{0,0} & P_{0,1} & - & - & P_{0,4} \\ P_{1,0} & P_{1,1} & P_{1,2} & - & P_{1,4} \\ - & P_{2,1} & P_{2,2} & P_{2,3} & P_{2,4} \\ - & - & P_{3,2} & P_{3,3} & P_{3,4} \end{pmatrix}$$

Some transition probabilities are not presented because they are considered as not "allowed", such as $P_{1,3}$. However, we observe in the data a few cases of transitions which are deemed impossible in the model. When we observe "impossible" transitions, we re-assign the final state to the closest state allowed. For example, if we observe a transition from state 1 to state 3 between $t-1$ and t, we re-assign the individual to state 2 in t.

We estimate first the initial $P_0|_{a,g}$ matrix from observed data. We then calibrate this matrix on observed death probabilities to obtain a $P_0^C|_{a,g}$ matrix. Thereafter, at each time t ($t > 0$), the matrix is calibrated on forecasted death probabilities and according to several scenarios. Thus, matrices include the calibrated probabilities P^c of switching from state i to state j. Such matrices run from 2015 (t=0) to 2060 (t=45), thus, there are 46 P^c matrices.

1.2. Death Probabilities by Age and Gender

We estimate the unconditional calibrated death probability $P^C_{t,.,4}$ using the demographic assumptions made by the French national institute for statistics for its population projections (Blanpain & Chardon, 2010).[3]

These projections provide death probabilities by age and gender at each time. We use those death probabilities to calibrate our death probabilities $P^C_{t,.,4}$ by gender and age at each time t (with the age and gender indices implicit here and in the notations below).

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[2] *The multilogit model assumes the Independence of Irrelevant Alternatives (IIA), according to which adding an option does not change the odds ratios. Since we only allow transitions to the closest states, it is not possible to increase the number of options. Thus, this assumption is not an issue in our model.*

[3] *These projections simulate, for each year up to a projection horizon, the number of men and women of each age, based on assumptions on the evolution of fertility, mortality and migration. Various scenarios are explored around a central scenario. In particular, the "young population" and "elderly population" scenarios use assumptions that lead, respectively, to the lowest and highest proportion of people aged 60 or over. Compared to the central scenario, death probabilities are lower at each age in the "elderly population scenario", and higher in the "young population" scenario, hence an older and a younger population, respectively.*

1.3. Calibration of Death Probabilities by Age, Gender and Disability State

At each time *t*, we allocate the calibrated overall death probability $P^C_{t,.,4}$ (i.e. regardless of the initial disability state) to conditional death probabilities $P_{t,i,4}$ (i.e. conditional on the initial disability state *i*, with $i \in \{0, 1, 2, 3\}$). The calibration relies on a parameter, $\lambda \in [0, 1]$ whose value is different according to the way death probabilities attenuation are allocated. We test three hypotheses regarding the allocation of unconditional death probabilities to conditional death probabilities: The first one assumes a homogeneous reallocation ($\lambda = \lambda^h$). The second and third assume an heterogeneous reallocation with either all the death probabilities attenuation assigned to the most autonomous states, states 0 and 1, ($\lambda = \lambda^a$) or assigned to the most disabled states, states 2 and 3 ($\lambda = \lambda^d$). We detail the three hypotheses below.

1.3.1. Homogeneous Allocation of the Decrease in Death Risks

The first hypothesis consists in allocating the decrease in death probabilities homogeneously to all disability states. It reflects a situation where the decrease in the overall death probability is due to a proportional decrease in death probability in each initial state. Importantly, it means that the odds ratios remain constant. In what follows, we use this hypothesis as a benchmark because it is the easiest to combine with the other hypotheses we made, and it is also a benchmark in other studies (see models cited by Comas-Herrera *et al.*, 2006 for example). Indeed, this assumption is the implicit one in all models that project first the death probability then apply the prevalence of the disability states to alive individuals. In these models, the prevalence of disability by age and gender remains constant over time. More recent models, such as the one presented by Kingston *et al.* (2018a) apply more refined prevalences for each dependency state depending on the scenario. While usual, this scenario is nonetheless pessimistic regarding the recent years. Indeed, it implies that a decrease in mortality at a given age leads to a proportional increase in the probability of disability (i.e. to be in states 1, 2 and 3) at this age. Overall, because of population ageing, this translates into a higher proportion of life spent in disability than in good health. In other words, the population ages but its probability to be dependent at each age remains constant.

Following this hypothesis, we homogeneously weight all the transition probabilities by a λ^h factor at each time. Hence, at each time $t \in [0, 45]$, we have:

$$P^C_{t,.,4} = \lambda^h_t \frac{N_{t,0}.P_{t,0,4} + N_{t,1}.P_{t,1,4} + N_{t,2}.P_{t,2,4} + N_{t,3}.P_{t,3,4}}{N_t}$$
$$= \lambda^h_t \frac{N_t.P_{t,.,4}}{N_t} \qquad (2)$$

with $P^C_{t,.,4}$ the unconditional calibrated death probability at time *t*. We note N_t the total population in *t* and $N_{t,i}$ the population initially in the disability state *i* in *t*, for any disability state 0, 1, 2, 3.

Note that Equation 2 is equivalent to:

$$\lambda^h_t = \frac{P^C_{t,.,4}}{P_{t,.,4}} \qquad (3)$$

Thus, λ^h_t is the ratio between the calibrated and uncalibrated death probability.

1.3.2. Heterogeneous Allocation of the Decrease in Death Risks

The second and third hypothesis, respectively "survival gains in autonomy" and "survival gains in disability", correspond to reallocating all the decrease in death probabilities either toward the most autonomous individuals (i.e. those in states 0 and 1) or toward those in the highest disability states (states 2 and 3).[4] These two extreme hypotheses are: *i)* A situation where death rate reduction is only due to a decrease in death risk for the most autonomous persons (for example, if the number of lethal road accidents decreases); *ii)* A situation where death risks decrease among disabled individuals only (for example, if the survival rate of people suffering from Alzheimer's increases because of medical progress). Those "extreme scenarios" show, other things being equal, the maximum magnitude that the reallocation of death probability decreases can have on the evolution of the number of dependent elderly and on morbidity. More balanced scenarios could define parameters that change the odds ratios between the four conditional probabilities $P_{t,i,4}$.

In the "survival gains in autonomy" scenario, any decrease in death probability entirely translates into a decrease in death probabilities among the most autonomous individuals (states 0 and 1). Thus, death probabilities do not change for those in the most disabled states (states 2 and 3).[5]

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[4] *Death probabilities are gender and age-specific, so that the re-allocations are only happening within each* age × gender *cell.*

[5] *Except in particular cases where there are not enough autonomous individuals of a given* age × gender *to absorb the predicted decreases in death probabilities.*

In this scenario:

$$\forall\ i \in \{0,1\}: P^c_{t,\,i,\,4} = P_{t,\,i,\,4} - \lambda^a_t \,.\, P_{t,i,4}$$

$$\forall\ i \in \{2,3\}: P^c_{t,\,i,\,4} = P_{t,\,i,\,4}$$

Hence:

$$N.P^c_{t,.,4} = N_0.P_{t,0,4} + N_1.P_{t,1,4} - \lambda^a_t.\left(N_0.P_{t,0,4} + N_1.P_{t,1,4}\right) + N_2.P_{t,2,4} + N_3.P_{t,3,4}$$

which leads to:

$$\lambda^a_t = \frac{N_t\,(P_{t,.,4} - P^c_{t,.,4})}{N_0.P_{t,0,4} + N_1.P_{t,1,4}}$$

with λ^a_t the ratio between survival gains and death rates of the most autonomous.

In the "survival gains in disability" scenario, all the decreases in death probability are allocated to the disability states.

$$\forall\ i \in \{0,1\}: P^c_{t,\,i,\,4} = P_{t,\,i,\,4}$$

$$\forall\ i \in \{2,3\}: P^c_{t,\,i,\,4} = P_{t,\,i,\,4} - \lambda^d_t.P_{t,\,i,\,4}$$

As a consequence, we have:

$$N.P^c_{t,.,4} = N_0.P_{t,0,4} + N_1.P_{t,1,4} + N_2.P_{t,2,4} + N_3.P_{t,3,4} - \lambda^d_t.\left(N_2.P_{t,2,4} + N_3.P_{t,3,4}\right)$$

which leads to:

$$\lambda^d_t = \frac{N_t\,(P_{t,.,4} - P^c_{t,.,4})}{N_2.P_{t,2,4} + N_3.P_{t,3,4}}$$

with λ^d_t the ratio between survival gains and death rates of the most disabled.

1.4. Adjustment of Transitions to States Other than Death

We then adjust transitions to states other than death, i.e. probabilities $P_{t,i,j}$, with $i \in \{0,1,2,3\}$ and $j \in \{0,1,2,3\}$. This corresponds to the path of autonomy loss, or recovery, if $j < i$.

By definition, for each initial disability state *i*, the sum of probabilities to move to all final states *j* has to sum to one, i.e.:

$$\forall\ \mathrm{t},\ \forall\ i \in \{0,1,2,3\}:$$

$$P_{t,i,0} + P_{t,i,1} + P_{t,i,2} + P_{t,i,3} + P_{t,i,4} = 1$$

with $P_{t,i,j}$ the probability to move from state *i* to *j* at time *t*.

In turn, calibrating conditional death probabilities induces to modify other probabilities to keep the sum of probabilities equal to 1:

$$\forall\ t, \forall i \in \{0,1,2,3\}\ :$$

$$P^c_{t,i,0} + P^c_{t,i,1} + P^c_{t,i,2} + P^c_{t,i,3} + P^c_{t,i,4} = 1$$

1.4.1. Homogenous Adjustment on Probabilities: Using a β *Factor*

We adjust transitions to states other than death in order to satisfy both constraints presented above. We adjust conditional transitions to death by a β_t parameter, such that, for all initial state $i \in \{0,1,2,3\}$:

$$\beta_{t,i}(P_{t,i,0} + P_{t,i,1} + P_{t,i,2} + P_{t,i,3}) + P^c_{t,i,4} = 1$$

which leads to:

$$\beta_{t,i} = \frac{1 - P^c_{t,i,4}}{1 - P_{t,i,4}}$$

In the case of an homogeneous calibration of conditional death probabilities, the formula is:

$$\beta_{t,i} = \frac{1 - \lambda_t P_{t,i,4}}{1 - P_{t,i,4}}$$

Such a setting boils down to the assumption that the odds ratios are preserved across transitions other than transitions to death. For a given initial state *i*, the reduction of $P_{t,i,4}$ induces that all $P_{t,i,j}$ probabilities (to $j \neq 4$) will increase proportionally.

This assumption enables to have a clear benchmark and a scenario easily comparable with our alternative scenarios. This hypothesis is implicitly made in many previous studies. However, we consider it as a pessimistic one. Indeed, while death probability decreases, transitions between other states remain similar, so that the relative risks of being in each disability state at a given age/gender remain constant. Therefore, we present a different assumption, where transition probabilities between disability states (other than death) are treated heterogeneously.

1.4.2. Heterogeneous Adjustment of Transition Probabilities: Example of an Increase in the Probability to Remain Autonomous

Our model allows the manipulation of each probability individually. Here, we turn to the possibility of modifying odds ratios between transition probabilities of individuals in an autonomous initial state. We consider the probability of staying autonomous $P_{0,0}$, which corresponds to the largest share of the observed flows in the data (see Section 2.2.1). We define a parameter α which impacts the probability to stay autonomous in such a way that this probability increases if $\alpha > 1$. Note that $P^c_{t,0,0} + P^c_{t,0,1} + P^c_{t,0,4} = 1$ so we adjust $P_{t,0,0}$ and $P_{t,0,1}$ such as to have:

$$P^c_{t,0,0} = \frac{\alpha\left(1 + \dfrac{P_{t,0,0}}{P_{t,0,1}}\right)}{1 + \left(\alpha\dfrac{P_{t,0,0}}{P_{t,0,1}}\right)}\, P_{t,0,0}$$

$$P^{c}_{t,0,1} = \frac{1+\dfrac{P_{t,0,0}}{P_{t,0,1}}}{1+\left(\alpha\dfrac{P_{t,0,0}}{P_{t,0,1}}\right)}P_{t,0,1}$$

Thus, we have:

$$\frac{\alpha\left(1+\dfrac{P_{t,0,0}}{P_{t,0,1}}\right)}{1+\left(\alpha\dfrac{P_{t,0,0}}{P_{t,0,1}}\right)}P_{t,0,0}+\frac{1+\dfrac{P_{t,0,0}}{P_{t,0,1}}}{1+\left(\alpha\dfrac{P_{t,0,0}}{P_{t,0,1}}\right)}P_{t,0,1}+\lambda_t P_{t,0,4}=1$$

If $P_{t,0,0}$ increases, the path into disability will slow down, because people stay autonomous for a longer period. A physical activity program for the autonomous elderly is an example of a public policy that could lead to such an evolution.

The transition probabilities from disability states 1, 2 and 3 are adjusted in an homogeneous way, following the method explained above.

In the scenarios presented in this paper, we calibrate the α parameter so that the ratio of disability-free life expectancy to total life expectancy at age 65 remains approximately constant (this is the case when $\alpha = 1.015$) or increases (when $\alpha = 1.03$). The credibility of this choice is discussed in the Online Appendix S1 (link of the Online Appendix at the end of the article). This working hypothesis corresponds to a high increase in the probability to stay autonomous, that may not be plausible given the trends observed in the past.

1.5. Assignment of a Disability State to Future Elderly

As our projections begin with a population aged 60 years, we need to assign an initial disability state to the newly 60 years old individuals who are simulated in our model. This assignment is made assuming that the prevalence of disability for the newly 60 years old decreases at the θ rate. Thus, considering that $S_0^{t_0}$ is the share of autonomous individuals in t=0, the share of elderly people with long-term care needs (states 2 and 3) at time t is computed so that:

$$1-S_0^{t}=(1-\theta)^{t-t_0}.\left(1-S_0^{t_0}\right)$$

Using SHARE data (waves 1 to 6), we estimate that θ is equal to 0.1. We keep this parameter constant through time.

1.6. Summary of Alternative Assumptions

Our microsimulation model allows making projections of the elderly disabled population under different scenarios, by combining the options to allocate the death probability decreases and to adjust the transitions to disability states other than death. These options and the corresponding parameters are summed up in Table 1. Comparing two scenarios that differ only in one parameter enables evaluating the weight of the parameter on the projection results.

2. Application: A Projection of the French Population in 2060

This section provides an illustration of the implementation of our model. We project the evolution of the French elderly disabled population, and explore the way each parameter affects the results. Our application relies on two surveys: The French survey CARE-M (2015) gives the initial prevalence of disability in the French population in 2015, and the European panel survey SHARE (2004 to 2017) the transition probabilities used to project the evolution of the French elderly disabled individuals in the population (see Box). We adjust our model to fit with the mortality forecast of the French National Institute of Statistics and Economic Studies (INSEE).

2.1. Scenarios

We present five scenarios which result from different combinations of the options summarized in Table 1.

In the baseline scenario, we project the number of individuals in each disability state considering an homogeneous allocation of mortality by initial disability state. We then homogeneously adjust the other transitions. In this scenario, the sources of life expectancy gains are not specific to individuals in a particular state of disability: it could result, for example, from an overall increase in investments made in hospitals, not targeting specific services.

Table 1 – **Summary of the options to define scenarios**

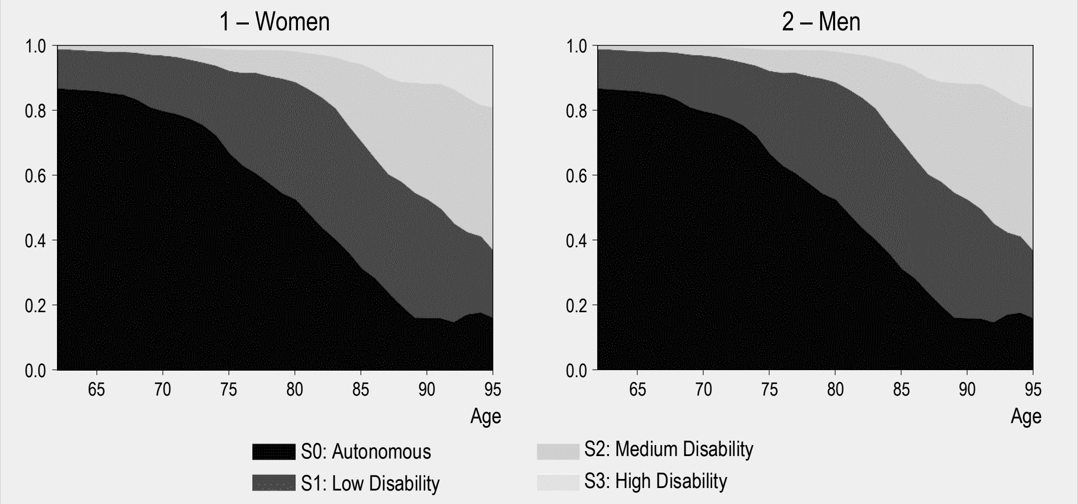
Options for allocating the death probability decrease to initial disability states ($P^{C}_{t,i,4}$)		
Homogeneous allocation (λ)	Allocation to autonomous states (λ^{a})	Allocation to disabled states (λ^{d})
Options for the adjustment on transitions other than death ($P^{C}_{t,i,j}$, $j \neq 4$)		
Homogeneous adjustment (β)	Heterogeneous adjustment (α)	

Box – **Data**

CARE-M survey :

The “Capacités, aides et ressources des seniors - Ménage” (CARE-M, Abilities, help, and wealth of the elderly - household) survey was collected in 2015 by the Ministry of Health. It is representative of the population aged 60 and over, living in ordinary housing (i.e. not in care or residential facilities for the elderly). This survey provides information on the socioeconomic characteristics and health of about 10,000 individuals. We use this data to measure the initial prevalence of disability by age and gender. We apply the weights provided in the survey, in order to account for the oversampling of individuals in bad health. Thus, the estimated prevalences are representative by age, gender and disability state.

Figure A – **Disability states by age in France**



Sample: All elderly aged 60 and over, living in the community in France, respondent to the health questionnaire. Figure A-1 is based on a sample of 6,519 women and Figure A-2 of 4,109 men.
Source: CARE-M, 2015.

Figure A shows that for both gender, the share of those who remain autonomous is higher than 80% at age 60. At age 90, 38% of men and 18% of women are autonomous. The higher prevalence of disability among women is partly explained by the well-known fact that women survive longer with disability than men.

SHARE :

The European Survey of Health, Ageing, and Retirement in Europe (SHARE) (Börsch-Supan, 2020) is a panel database providing information on the population aged 50 and over, living in one of the 21 European countries included in the survey. The first wave was collected in 2004/2005.

We use data from waves 4, 5 and 6 (respectively conducted in 2011, 2013 and 2015). We restrict our sample to individuals from countries surveyed in waves 4, 5 and 6, living in ordinary housing, who answer questions on health and are observable at least in two consecutive waves (i.e. 4 and 5 or 5 and 6). Due to these restrictions, we consider individuals from 13 countries: Austria, Belgium, Czech Republic, Denmark, Estonia, France, Germany, Italy, Netherlands, Slovenia, Spain, Sweden and Switzerland. Including those countries in the sample instead of France allows us to measure a large range of disability states, while keeping a sufficient statistical power.

The target population (for the first wave) is people born in 1954 or earlier and their partner if any, independently from his/her age. Health questions are slightly different in SHARE and in CARE-M.

We select, as in the CARE-M data, the elderly aged 60 and over. We rely on SHARE data to estimate the $P|a,g$ matrix, the probability to switch from state i to state j, for each age a and gender g. We do not use SHARE individual weights, as probabilities are conditional on age, gender and country. Those transition probabilities are then calibrated to match mortality forecasts, as described in Section 1.2.

The Online Appendix S2 provides additional information regarding SHARE data, our sample and the choices we made to harmonize the SHARE and CARE-M datasets population projections.

We use the French National Institute of Statistics and Economic Studies (INSEE) mortality projections in order to align our microsimulation model with credible demographic targets (Blanpain & Buisson, 2019). We rely on the projections from 2013; more recent ones are available but they were made later than the year at which we measure initial prevalence, in 2015. We consider the demographic central scenario, which corresponds to the standard population projection. The underlying hypotheses in terms of life expectancy, fertility and migration are detailed in Table A. We use the age×gender death probabilities to calibrate death probabilities $P^{C}_{t,.,4}$ by gender and age at each time t. ➔

Box – *(contd.)*

Table A – **Demographic assumptions from 2015 to 2060**

	Young population	Central population	Old population
Life expectancy Women	88.6 y.o.	91.1 y.o.	93.6 y.o.
Life expectancy Men	83.5 y.o.	86.0 y.o.	88.5 y.o.
Fertility index	2.1	1.95 from 2015	1.8
Net migration	+150,000	+100,000	+50,000

Note: Demographic assumptions underlying the young population imply that women's (resp. men's) life expectancy is 88.6 years old (resp. 83.5); fertility index is 2.1 and net migration is 150,000 individuals.
Source: Blanpain & Chardon (2010).

On the contrary, the "autonomy" and "disability" scenarios are extreme cases of death probability decreases resulting from targeting particular populations (either in good health or in bad health). For example the "autonomy" scenario could correspond to a situation where a national prevention campaign aims at detecting breast cancers among women. It raises life expectancy of individuals who are relatively autonomous. On the other hand, the "disability" scenario could reflect the decision to invest in the care of individuals affected by the Alzheimer disease, or in research for treatments. Technically, both scenarios correspond to a different allocation of the decrease in death probability, and a related change of the parameter. Note that this approach is more flexible than that of Leaf *et al.* (2020), who uniformly apply a "reduction factor" to death probabilities to capture the effect of medical innovation. On the contrary, we allow here death probabilities to vary depending on the initial disability state.

The last two scenarios, "remain autonomous", consist in increasing the probability to remain autonomous, while keeping other parameters constant. It could correspond for example to a national campaign fostering physical activity among the elderly. The "Remain autonomous scenario – 1.5% increase" consists in setting the annual increase in the probability to remain autonomous to 1.5%. In this setting, the ratio disability-free life expectancy over total life expectancy (hereafter DFLE/LE) at age 65 remains approximately constant in our simulations. The "Remain autonomous scenario – 3% increase" relies on a 3% increase of this probability.

The scenarios and assumptions made for each of them are presented in Table 2, and a reminder of the model parameters is provided in Table 3.

Our baseline scenario relies on rather pessimistic assumptions. In particular, a homogeneous allocation of the death probability decrease across all states implies that, when life expectancy

Table 2 – **Definition of five scenarios**

Scenario	Option 1 Allocation of mortality decrease	Option 2 Adjustment of other transitions
Baseline	Homogeneous	Homogeneous
Survival gains in autonomy	Autonomy	Homogeneous
Survival gains in disability	Disability	Homogeneous
Remain autonomous – 1.5% increase	Homogeneous	Heterogeneous
Remain autonomous – 3.0% increase	Homogeneous	Heterogeneous

Table 3 – **Parameters of the model**

Parameter	Definition	Formula
λ	Weight applied to mortality probabilities	$\lambda = \frac{P_4^{INSEE}}{\sum P_{i,4} N_i}$
μ	Proportion of life expectancy gains attributed to autonomy states	$\mu = 0$ or $\mu = 1$
β	Weight applied to transitions between dependency states	$\beta = \frac{1 - \lambda . P_{i,4}}{1 - P_{i,4}}$
α	Change in the probability to remain autonomous	$\alpha = 1$ or $\alpha = 1.015$ or $\alpha = 1.03$
θ	Decrease (in %) of the share of dependent 60 years old	Exogenous, $\theta = 0.1$

Note: P_{i4} is the probability to die for someone in dependency state *i*, N_i the population in state *i*, P^{INSEE} are INSEE projections for mortality.

increases, it translates into a higher share of disability-free life expectancy.

Such an assumption is implicitly made in several studies, for example those cited by Comas-Herrera *et al.* (2006). It is a key assumption, as elderly disability projections largely depend on the source of life expectancy gains. Here we make this assumption explicit in the model; we then show to what extent this choice impacts the disabled population projection.

2.2. Results

In this section we present the results of our microsimulation model application. We first present transition probabilities estimated using SHARE data, then, the projected evolution of the elderly disabled population under the scenarios defined above.

2.2.1. Transition Probabilities

Table 4 presents the mean probabilities to switch from one disability state to another, conditionally on observed characteristics (age and gender).[6]

Our transition probabilities are estimated on a sample of 13 European countries, which allows us reaching an acceptable statistical power to estimate transitions in a 5-level scale. But this can have several downsides from other points of view. We therefore carry out various robustness tests. Firstly, we test whether this sample is representative of the French case, by comparing the transition probabilities measured for the whole sample and for the sample restricted to French individuals (see Online Appendix S3, section 2). We also want to ensure that our results are not sensitive to specificities of some of the 13 selected countries. A comparison of the baseline transition probabilities with estimates from alternative samples of countries shows that it does not modify our main results (see Online Appendix S3, section 3). We also check that including more control variables in the estimation does not modify those results (see Online Appendix S3, section 4). Finally, we check that, when some transitions to non-nearby states are identified and modified, only a small share of our sample is concerne. We check that our results are robust to those modifications (see Online Appendix S3, section 5).

The disablement process varies across gender. Online Appendix S4 provides additional results, first by splitting the sample between men and women (see Table S4-1 in Online Appendix S4). Gender differentials are more striking for the two highest states of disability, especially regarding death probabilities.

As transition probabilities have changed over the last few years, using old waves of the SHARE data could be detrimental to the estimation of the disablement process. We consider using SHARE oldest waves rather the most recent ones (see Table S4-2 in Online Appendix S4), which only leads to small changes.

2.2.2. Projection of the Elderly Disabled Population

We provide now some illustrations of the results that can be obtained using this microsimuluation model, considering how many elderly disabled individuals are projected until 2060 and how those projections vary by scenario. We use the previously mentioned age×gender-specific transition probabilities, recalibrating death probabilities using INSEE mortality forecasts for each year. For example, the first step consists in recalibrating the 2015 death probabilities to be equal to death probabilities provided in population forecast given by INSEE 2015 from its central demographic scenario.

Figure II shows the evolution of the number of disabled individuals under the baseline scenario, where life expectancy gains are homogeneously reallocated between disabled states. Our projections lead to estimate that in 2060, 2.7 million

Table 4 – **Probabilities of transition between disability states, estimated with SHARE Data**

	Autonomy (S0)	Disability			Death (S4)
		Low (S1)	Medium (S2)	High (S3)	
S0	0.82	0.16	x	x	0.02
S1	0.34	0.36	0.23	x	0.07
S2	x	0.33	0.27	0.26	0.13
S3	x	x	0.27	0.50	0.23

Notes: The estimated probability to remain autonomous is 82%. An individual with low disability (S1) has a 34% probability to recover autonomy (S0), 36% to remain lowly disabled, 23% to become medium disabled (S1) and 7% of dying (S4).
Sample: Elderly aged 60 and over, in one of the 13 countries included (cf. Box), responding to the health questionnaire at least in two consecutive waves. We exclude spouses from the sample.
Source: SHARE waves 4, 5 and 6.

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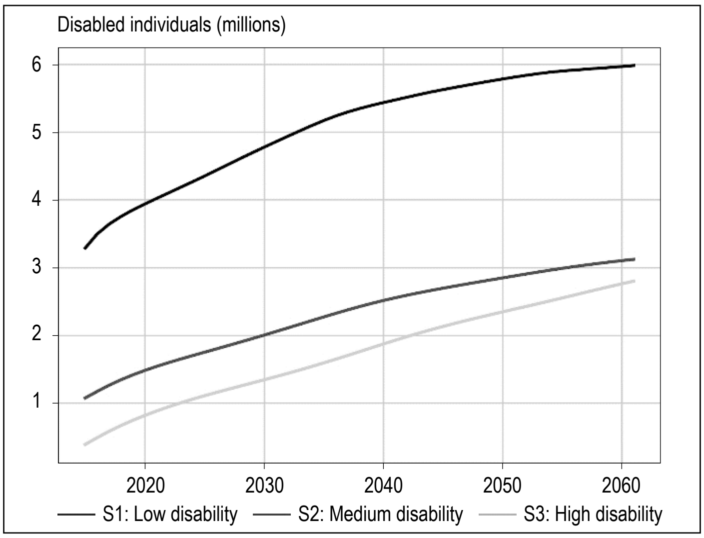
[6] *As an example, we also present adjusted predictions of our multinomial Logit models for a 70 years old woman and a 70 years old man in the Online Appendix S3, section 1.*

Figure II – **Evolution of disability in the French population aged 60 or more, baseline scenario**



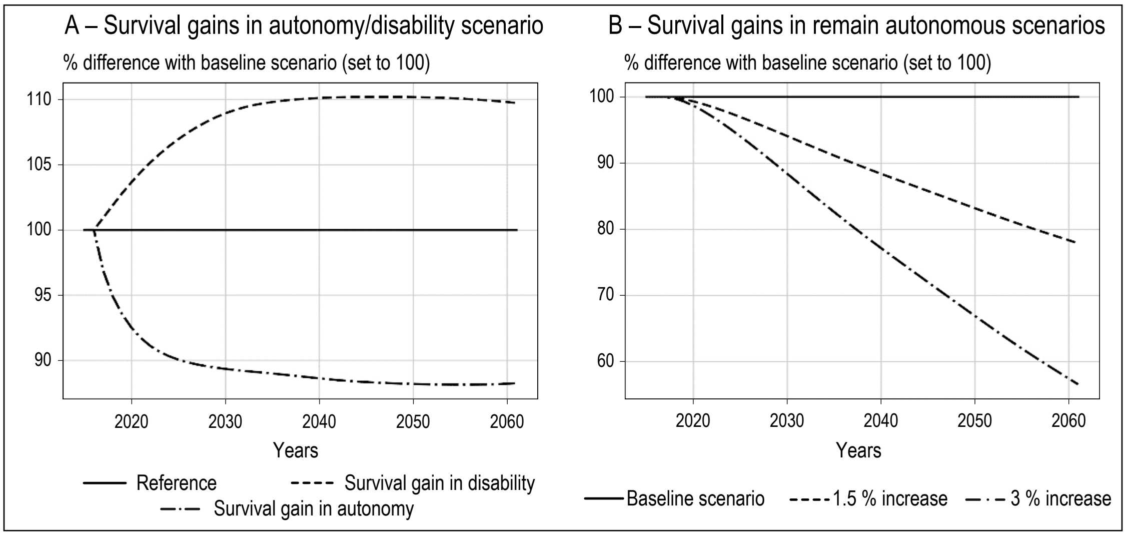
Sample: All elderly aged 60 and over, in one of the 13 countries included (See Table S2-2 in Online Appendix S2), respondent at least in two consecutive waves, and respondent to the health questionnaire. We exclude spouses from the sample.
Source: SHARE Waves 4, 5 and 6.

people will be highly disabled (state 3, meaning that they have at least one functional limitation, one IADL and one ADL). This forecast is more pessimistic than the French projection relying on an administrative approach to disability (for example, Charpin & Tlili (2011) forecast about 2.3 million disabled people). It is consistent with the idea that epidemiological measurement of disability accounts for individuals who would not seek any allowance.

Figure III shows the evolution of the number of disabled individuals (defined as those in states 2 and 3, i.e. with IADL or ADL limitations) among those aged 60 or more across the scenarios. We set the baseline scenario at 100 so that any divergence corresponds to the difference between the projection of a scenario and the baseline scenario.

Firstly, we compare the projection of the baseline scenario to the "survival gains in autonomy" and in "survival gains in disability" scenarios (Figure III-A). The "survival gains in autonomy" scenario leads anticipating 15% less disabled individuals in 2060 than the baseline scenario.

Figure III – **Evolution of disability (IADL or ADL limitations) in the population 60+, by scenario**



Notes: Figure A: Disability includes people in states 2 or 3. In 2060, the scenario "survival gains in disability" leads to a forecast of 1.1 times more dependent individuals than with the baseline scenario. The scenario "survival gains in autonomy" leads to a forecast of 1.11 times less dependent than with the baseline scenario. Figure B: In 2060, the scenario "1.5% increase in the probability to stay autonomous" leads to a forecast of 1.28 times less dependent individuals than with the baseline scenario. The scenario "3% increase" leads to a forecast of 1.81 times less dependent than with the baseline scenario. Mechanically, when we do not modify the probability to stay autonomous, the difference with the baseline scenario is null.

As the death probability of autonomous individuals decreases, because all survival gains are allocated to them, they remain for a longer period in the autonomous state. The projected number of disabled people is smaller than in the baseline scenario. The death probability decreases in the disability scenario leads in 2060 to a population including 10% more elderly disabled individuals than in the baseline scenario. This is due to the fact that the life expectancy of disabled individuals increases. Around 2030, the difference between both scenarios and the baseline remains constant, because of the gradual arrival of the baby-boomers in the states of disability. In the baseline scenario, the number of disabled individuals is important from 2030 onwards, which implies that the difference with both scenarios remains constant afterwards.

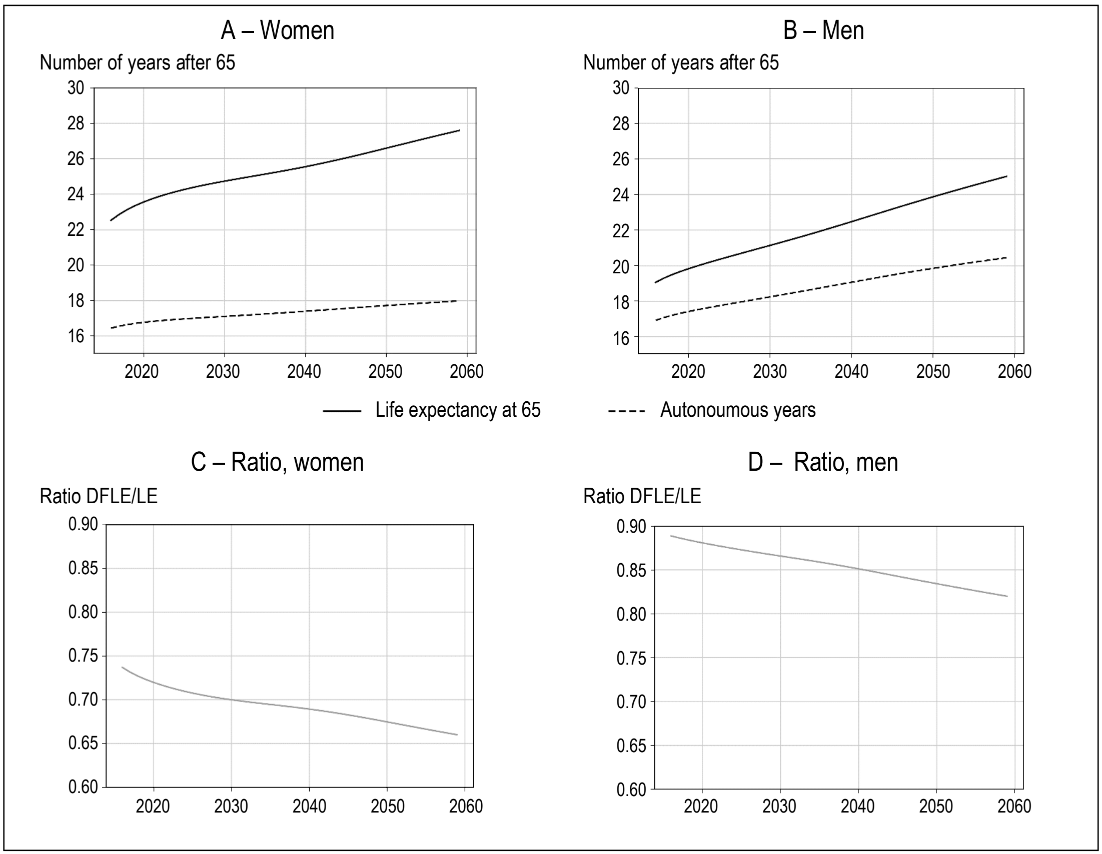
Then, we compare the baseline scenario projections to the "remain autonomous" scenarios (Figure III-B). The first scenario, where we set the annual increase of the probability to remain autonomous at 1.5% (so that the DFLE/LE ratio at age 65 remains approximately constant), leads anticipating 20% less disabled individuals than the baseline scenario, where the probability to remain autonomous is constant over time. Setting the increase in the probability to 3% results in about 45% less disabled individuals.

Those results rely on the demographic assumptions of the INSEE's central scenario. In order to test the sensitivity of our results to the demographic assumptions we rely on, we have adopted alternatively the assumptions of the "young population" and "old population" scenarios of the INSEE's projections (cf. Box and Table A). These assumptions lead to shares of disabled individuals (i.e. in states 2 and 3) which are 12% lower and 20% higher, respectively, than those obtained using the demographic assumptions of the central scenario. These results are presented in the Online Appendix S4.

2.2.3. Projection of the Morbidity Trends

We now turn to the projected evolution of the disability-free life expectancy compared to the overall life expectancy. We compute the disability-free life expectancy to total life expectancy ratio at age 65. Disability-free years are all the

Figure IV – **Overall and disability-free life expectancy at age 65, baseline scenario**



Note: In the reference scenario, disability-free life expectancy for women is around 16.5 years in 2015, rising to 17.9 years in 2060, while total life expectancy varies from 22.5 years to 27.5 years in 2060. The ratio of these two variables was 74% in 2015, rising to 65% in 2060. The disability-free life expectancy, respectively total life expectancy, of men varies from 17, respectively 19, in 2015 to 20.5, respectively 24.7. The ratio therefore falls from 89% to 82%.

years spent in states 0 or 1, i.e. without any IADL or ADL limitation.

Figure IV shows the expected number of autonomous years at age 65 compared to the overall life expectancy at age 65 in the baseline scenario. For men, the projection for 2060 leads anticipating that, on average at age 65, disability-free years will represent 20.5 of the 24.7 years expected to remain to 2060. It corresponds to a DFLE/LE ratio equal to 0.82. For women, in 2060 this ratio lowers to 0.65 as they are expected to live 17.9 disability-free years in the 27.5 years expected.

Those forecasts are relatively pessimistic, in line with the pessimistic assumptions chosen. Indeed, disability-free life expectancy is forecasted to increase less rapidly than life expectancy, especially for women. Previous observations of the trends are the reverse: Cambois *et al*. (2008) show that, between the 1980s and 2002-2003 and for men and women, disability-free life expectancy (considering only severe disability) increased more than total life expectancy.

Several previous studies projecting the evolution of the number of disabled elderly individuals assumed in their central scenario that the DFLE/LE ratio would remain constant (Lecroart *et al*., 2013; Marbot & Roy, 2015; Roussel, 2017).

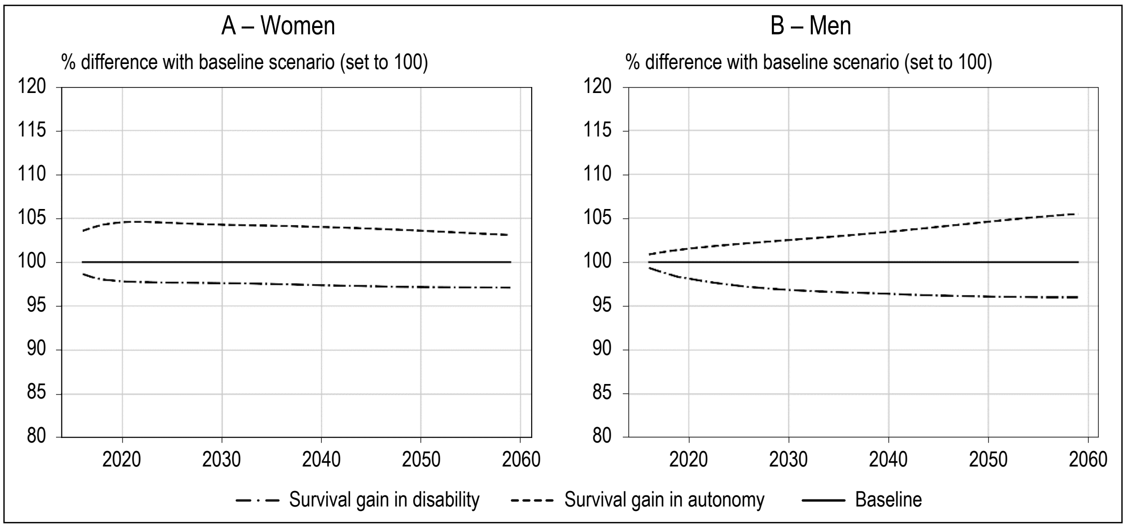
We now examine whether more optimistic assumptions result in a projected DFLE/LE ratio more in line with previous trends and studies.

Figure V presents a comparison of the evolutions of the DFLE/LE ratio with the death probability decreases allocated to autonomy or to disability (the baseline scenario is here again set to 100), separately for women and for men. For men, the scenario in which all the gains are allocated to autonomous individuals leads to forecasting a ratio 5% higher than in the baseline scenario projection (Figure V-B). As disability-free life expectancy increases more rapidly than overall life expectancy, the ratio increases as well. Logically, the scenario in which all the decrease in death probability is allocated to disability results in forecasting a ratio 5% smaller than in the baseline scenario. For women (Figure V-A), the divergence from the baseline scenario is smaller, with a difference of 2 or 3% for each scenario, and less symmetric.

Finally, we examine the DFLE/LE ratio when varying the probability to remain autonomous. For women (Figure VI-A), the increase of 1.5% of the probability to remain autonomous raises the DFLE/LE ratio by 10% in 2060 compared to the baseline scenario. The impact for men (Figure VI-B) is twice smaller, around 5% in 2060. In the scenario where the increase in the probability to remain autonomous is set to 3%, the DFLE/LE ratio is higher by 23% for women in 2060, and 14% for men.

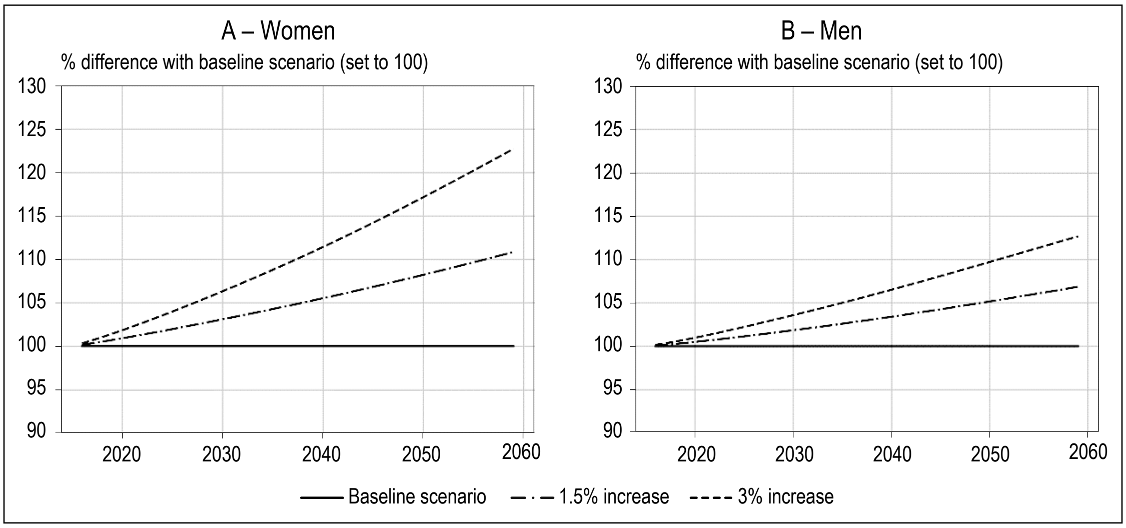
We present the same comparisons for demographic scenarios by measuring, for the "young population" and "old population" scenarios, the DFLE/LE ratio. (see Figure S4-I, in the Online Appendix S4), to illustrate again how the demographic assumptions influence those projections. The "young population" scenario leads to a 4% (resp. 2.5%) higher DFLE/LE ratio among women (resp. men), and the "old population" scenario to a 5% (resp. 2.5%) lower

Figure V – **Disability-free life expectancy to total life expectancy ratio after age 65 by survival gains allocation scenario**



Note: In 2060, considering the "survival gains in autonomy" scenario, the ratio of disability-free life expectancy to total life expectancy is projected to be 5% higher than in the baseline scenario for men.

Figure VI – **Disability-free life expectancy to total life expectancy ratio after age 65 according to the increase in the probability to remain autonomous**



Note: In 2060, considering the "1.5% increase" scenario, the ratio life expectancy in good health over total life expectancy is projected to be 10% higher than in the baseline scenario for women.

ratio for women (resp. men). We conclude that modifying our main demographic assumptions, using different life expectancy forecasts (young, central or old population) does not drastically modify our main baseline scenario results.

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*

This article aims at improving the understanding concerning scenarios that might drive a compression or expansion of morbidity. For example, how the decrease in death probability impacts the disability-free life expectancy to total life expectancy ratio, or how the evolution of the prevalence of disability affects this ratio. To this aim, we develop a new methodological approach to project the increase in long-term care needs within ageing populations. A key assumption is related to how life expectancy gains are allocated to the different disability states. We estimate transition rates between several disability states, in order to make this key assumption explicit. The model enables to isolate the effect of each parameter. Therefore, it could be used to estimate the long-run impact on the disabled population of a breakthrough in medicine, a pandemic or a national prevention policy, by assuming which transition probability these events will affect.[7]

In our application study, we project the evolution of the French elderly disabled population in 2060. We use the European panel survey SHARE to estimate the transition probabilities from one disability state to another, and the French survey CARE-M to determine the initial prevalence of each disability state in the French population of elderly aged 60 and over and living in ordinary housing (i.e. not in care or residential facilities).

We show that assumptions to allocate death probability decreases between disability statuses do influence the disability forecast: the projected number of elderly disabled people varies by +/−10% compared to the baseline scenario each year, and the DFLE/LE ratio varies by +/−5%. The assumptions related to the evolution of the probability to stay autonomous have a larger impact on the projection, with a decrease of around −20% of disabled individuals when the probability to remain autonomous increases by 1.5% each year. The DFLE/LE ratio increases by 5% in this case.

Our application has two main limitations. First, the number of explanatory variables used for the estimation is limited, as only age and gender are controlled for. Second, our analysis focuses on individuals living in ordinary housing, i.e. excluding those who live in care facilities, who might present higher degrees of disability. This could lead to an underestimated forecast of the share of disabled. However, this may have only a limited impact, since the share of elderly people living in a nursing home is 4% (Carrère & Roy, 2020). Time spent in a nursing home is also relatively short, with half of the stays lasting less than 1.5 year and three quarters of the stays last less than four years (Fizzala, 2017).

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[7] *The software package is available upon request.*

More generally, our application highlights that building a plausible scenario requires to work in details on the past evolution of specific parameters, in order to make assumptions on their evolution. Specific hypotheses about the evolution of medical and sanitary care make also possible to build scenarios regarding the evolution of disability. The strength of microsimulation is only marginally exploited in this paper, as we use a limited set of covariates – one could well apply macrosimulation or cell-based simulations instead. But, as a methodological contribution, it shows the potential of this approach. Further research is required to build such scenarios relying on plausible assumptions. Moreover it should be highlighted that those results do not provide answers to the question whether the projected demand for care will be satisfied or not. The decline in the availability of caregivers might limit this goal. Further research regarding the evolution of formal and informal care supply could help to build public policies. ☐

Link to the Online Appendix:
www.insee.fr/en/statistiques/fichier/7615301/02_ES538_BenJelloul-et-al_OnlineAppendix.pdf

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APPENDIX

LITERATURE AND DEFINITION OF DISABILITY STATES

1 – Measure of Disability in Previous Studies

Our choice of disability scale relies on epidemiological publications studying the relevant measure of the process of loss of autonomy. Since no gold standard exists on this question, this choice varies from one study to another.

Some studies forecasting disability accounted for functional limitations but fewer states were considered. Some of them relied on three states, being “having no limitation”, “having limitations” and “death” (Cambois & Robine, 2014); others on four disability states: “autonomy”, “functional limitations”, “limitation in activity daily living” and “death” (Cambois & Lièvre, 2007; Crimmins *et al.*, 2009).

Several other studies also accounted for five possible states in the disability scale, however with different definitions, excluding fonctional limitations or by considering a larger scope. For example, in Spijker *et al.* (2022), low dependency is defined as having “disability reported but no problems stated in carrying out ADL/IADL”, medium dependency as “one ADL and/or any IADL” and high dependency as “at least two ADL”. Cai & Lubitz (2007) only rely on limitations in ADL / IADL: low disability consists in having at least one IADL but no ADL, moderate disability is being disabled in one or two ADLs and severe disability is being disabled in at least three ADLs.

2 – Definition of Disability States

Table A2 – **Definition of dependency**

Scale	Name	Due to health problem, have at least one difficulty with:
State 0	Autonomy	None of the mentioned activities
State 1	Rosow limitation	Walking 500 meters Climbing one flight of stairs Lifting or carrying weight over 5 kg
State 2	IADL limitation	Making telephone calls Shopping for groceries Taking medications Managing money For women only: preparing a hot meal For women only: doing work around the house or garden
State 3	ADL limitation	Bathing or showering Dressing, including putting on shoes and socks Using the toilet, including getting up or down Getting in or out of bed Eating, cutting up food
State 4	Death	