Health Status and Functional Disability with Systematic Trends: A Comparison of China and the USA

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Motivation

Increasing demand of LTC

Reason of arising LTC burden

- Accelerating ageing process
- Declining fertility
- Ineffectiveness of self-insure
- Improving survival rate of the oldest elderly

Figure 1: No. of disabled elderly (Million)

Early stage of studies on health status transition rates of China

Studies among other populations provide suggestive insights

- Significant trend improvement in incidence of disability
- Necessity of taking uncertainty into account

Our contribution

- Follow Li, Shao, and Sherris (2017) to estimate the health status transition rates of disabled elderly incorporating trend and uncertainty impact for China.
- Provide interesting perspectives by comparing with the USA analysis with the same model.

Questions we will answer

Factor impacts

- Whether the compression of disability, improvement of recovery, improvement of healthy mortality and disabled mortality exist?
- What's the role the uncertainty plays in the health status transitions?
- How big is the gap of the disability rate among female and male, urban and rural residence?
- Factor impact comparison with the USA.

Influence on the life path of individuals

- How does the gap between disabled mortality and healthy mortality goes as time pass?
- How does the probability of being disabled change in the life path of a certain healthy individual
- How does the ratio of years spent in disabled to total life expectancy change?
- Are people living longer active lives as well as longer lives?
- The similarity and difference of the influence compared with the USA.
Outline

Model Specification
  Three-state disability model
  Intensity function

Estimation methodology
  Parameter Estimation: MLE

Definition of disability and data

Estimation results
  Estimation of the latent factor
  Parameter Estimates and analysis of factor impact
  Analysis of influences on an individual's life path
    Simulated Transition Rates
    Simulated probability of being disabled
    Simulated life expectancy
    Simulated active survival curves

Summary of findings
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Summary of findings
Three-state continuous time Markov model

Three-state disability model with recovery

- Two transition states
  - Healthy (H)
  - Incident of disability (I)
- One absorbing state
  - Dead (D)

(Could easily be extended by splitting the disabled state to more states)

Continuous time Markov process

- The conditional distribution of future states depend on the current state
- Transition rates are allowed to update any time during the survey spell when the transition happens.
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Summary of findings
Specification of the intensity function

Adopt the Cox proportional hazards specification (Cox 1992)

The conditional transition intensity for individual k of transition type s at time t:

\[ \lambda_{sk} = \exp[\beta_s + \gamma_s \omega_k(t) + \xi_x \cdot \psi(t)] \cdot H_{sk}(t) \]  \hspace{1cm} (1)

\( \omega_k(t) \), vector of the observed covariates for each individual k (Age, gender and residence, time).

\( \psi(t) \), the unobserved latent factor (Frailty).

\( H_{sk}(t) \), the baseline hazard function to allow for duration dependence (Set to 1).

Static model (Reference level)

\[ \ln \lambda_{skx} = \beta_s + \gamma_s^{age} \cdot x + \gamma_s^{female} \cdot F + \gamma_s^{urban} \cdot U \] \hspace{1cm} (2)

Time trend model

\[ \ln \lambda_{skx}(t) = \beta_s + \gamma_s^{age} \cdot x + \gamma_s^{female} \cdot F + \gamma_s^{urban} \cdot U + \phi_s \cdot t \] \hspace{1cm} (3)

Frailty model

\[ \ln \lambda_{skx}(t) = \beta_s + \gamma_s^{age} \cdot x + \gamma_s^{female} \cdot F + \gamma_s^{urban} \cdot U + \phi_s \cdot t + \alpha_s \cdot \psi(t) \] \hspace{1cm} (4)

1. Health status, 1-3; k - the kth individual; x - age.
2. x - age, 1-3; F, U - indicator variables, female, urban; t - time; \( \psi \) - the latent factor
3. Note that \( \psi \) is the same for all transition types.
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Adopt the Cox proportional hazards specification (Cox 1992)

The conditional transition intensity for individual $k$ of transition type $s$ at time $t$:

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Time trend model

$$\ln \lambda_{skx}(t) = \beta_s + \gamma_s^{age} \cdot x + \gamma_s^{female} \cdot F + \gamma_s^{urban} \cdot U + \phi_s \cdot t \quad (3)$$

Frailty model

$$\ln \lambda_{skx}(t) = \beta_s + \gamma_s^{age} \cdot x + \gamma_s^{female} \cdot F + \gamma_s^{urban} \cdot U + \phi_s \cdot t + \alpha_s \cdot \psi(t) \quad (4)$$

1. $s$-Health status, 1-3; $k$- the $k$th individual; $x$- age.
2. $x$-age, 1-3; $F, U$-indicator variables, female, urban; $t$-time; $\psi$-the latent factor
3. Note that $\psi$ is the same for all transition types
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Summary of findings
Parameter Estimation: Maximum Likelihood

Notation

- $Y_{sk}(t)$ - whether a transition happens at time $t$, if so, $Y_{sk}(t) = 1$;
- $R_{sk}(t)$ - whether exposed to transition risk between $t-1$ to $t$, if so, $R_{sk}(t) = 1$.

The ML function

- **Static and Time trend model**

  \[
  L(\theta|\mathcal{F}_T)_{\text{timeTrend}} = \prod_{t=1}^{T} \prod_{k=1}^{K} \prod_{s=1}^{S} \exp\{Y_{sk}(t) \cdot \ln[\lambda_{skx}(t)] - R_{sk}(t) \int_{t-1}^{t} \lambda_{skx}(u) du\} \]

- **Frailty model**

  **Conditional ML function**

  \[
  L(\theta|\mathcal{F}_T, \Psi)_{\text{frailty}} = \prod_{t=1}^{T} \prod_{k=1}^{K} \prod_{s=1}^{S} \exp\{Y_{sk}(t) \cdot \ln[\lambda_{skx}(t)] - R_{sk}(t) \int_{t-1}^{t} \lambda_{skx}(u) du\} \]

  **Unconditional ML function**

  \[
  L(\theta|\mathcal{F}_T)_{\text{frailty}} = \int L(\theta|\mathcal{F}_T, \Psi) dP(\Psi) = \frac{1}{N} \sum_{m=1}^{N} L(\theta|\mathcal{F}_T, \Psi^m) \]

Monte Carlo simulation is used to generate the latent factor to get the simulated estimator of the ML function.
Definition and data

Definition of disability: Functional disability
Evaluate the inability to perform basic self-care activities without assistance
- Commonly used trigger of LTCI.
- Evaluated by Activities of Daily Living (ADL), including bathing, dressing, toileting, transferring, continence, feeding.
- Categorised as disabled when having difficulties in 2 or more of the 6 ADLs.

Data: Chinese Longitudinal Healthy Longevity Survey, 1998-2011
- Interviewees: the elderly aged 65 and above in 22 provinces.
- Samples: 42155 individuals.
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Summary of findings
Recovery of the latent factor

Recovery: Kalman Filter

- Follow Li, Shao, and Sherris (2017) to use the state space model to link the observation indicator $Y_{s,k,t}$ to the $\ln \lambda_{s,k,t}$.
- Using Gaussian distribution to estimate $Y$’s non-Gaussian distribution.

Posterior mean of latent frailty factor

Figure 2: Posterior mean of latent frailty factor

(a) China

(b) US
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Summary of findings
# Parameter estimates for China

## Table 1: Parameter estimates for the frailty model

<table>
<thead>
<tr>
<th>Transition Type</th>
<th>H-I</th>
<th>I-H</th>
<th>H-D</th>
<th>I-D</th>
</tr>
</thead>
<tbody>
<tr>
<td>s= 1</td>
<td>-8.8398***</td>
<td>-0.7123*</td>
<td>-9.5553***</td>
<td>-6.6308***</td>
</tr>
<tr>
<td>s= 2</td>
<td>0.1655</td>
<td>0.3712</td>
<td>0.0879</td>
<td>0.1765</td>
</tr>
<tr>
<td>s= 3</td>
<td>0.0670***</td>
<td>-0.0171***</td>
<td>0.0863***</td>
<td>0.0606***</td>
</tr>
<tr>
<td>s= 4</td>
<td>0.0017</td>
<td>0.0039</td>
<td>0.0009</td>
<td>0.0018</td>
</tr>
<tr>
<td>s= Frailty</td>
<td>0.1833***</td>
<td>0.0571</td>
<td>-0.2866***</td>
<td>-0.2083***</td>
</tr>
<tr>
<td>s= Female</td>
<td>0.0331</td>
<td>0.0699</td>
<td>0.0164</td>
<td>0.0273</td>
</tr>
<tr>
<td>s= Urban</td>
<td>0.3333***</td>
<td>-0.2204***</td>
<td>-0.0600***</td>
<td>-0.0576***</td>
</tr>
<tr>
<td>s= Time Trend</td>
<td>-0.0855***</td>
<td>-0.0868***</td>
<td>0.0060**</td>
<td>-0.0136***</td>
</tr>
<tr>
<td>s= Log Likelihood</td>
<td>-75461</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Static Log Likelihood</td>
<td>-75669</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Trend Log Likelihood</td>
<td>-75525</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The significant level are marked as *p < 0.1; ** p < 0.05; ***p < 0.01. Similarly hereinafter. The parameter estimated is for annual rates. 1000 paths of $\phi$ is generated for the frailty model.
Table 2: Parameter estimates of model without residence variable

<table>
<thead>
<tr>
<th>Transition Type</th>
<th>H-I</th>
<th>I-H</th>
<th>H-D</th>
<th>I-D</th>
</tr>
</thead>
<tbody>
<tr>
<td>s</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>( \beta_s )</td>
<td>-8.6576***</td>
<td>0.1502</td>
<td>-10.5629***</td>
<td>-6.9249***</td>
</tr>
<tr>
<td>( \sigma_{\beta} )</td>
<td>0.1108</td>
<td>0.1299</td>
<td>0.1173</td>
<td>0.1502</td>
</tr>
<tr>
<td>( \gamma_{\text{age}} )</td>
<td>0.0682***</td>
<td>-0.0318***</td>
<td>0.1015***</td>
<td>0.0648***</td>
</tr>
<tr>
<td>( \sigma_{\gamma_{\text{age}}} )</td>
<td>0.0014</td>
<td>0.0017</td>
<td>0.0014</td>
<td>0.0018</td>
</tr>
<tr>
<td>( \gamma_{\text{female}} )</td>
<td>0.2898***</td>
<td>0.0491</td>
<td>-0.4566***</td>
<td>-0.3778***</td>
</tr>
<tr>
<td>( \sigma_{\gamma_{\text{female}}} )</td>
<td>0.0284</td>
<td>0.0400</td>
<td>0.0271</td>
<td>0.0357</td>
</tr>
<tr>
<td>( \phi_s )</td>
<td>-0.0039</td>
<td>0.0058</td>
<td>-0.0388***</td>
<td>0.0023</td>
</tr>
<tr>
<td>( \sigma_{\phi_s} )</td>
<td>0.0042</td>
<td>0.0056</td>
<td>0.0040</td>
<td>0.0053</td>
</tr>
<tr>
<td>( \alpha_s )</td>
<td>0.0121</td>
<td>0.0287***</td>
<td>-0.0207**</td>
<td>0.0134</td>
</tr>
<tr>
<td>( \sigma_{\alpha_s} )</td>
<td>0.0084</td>
<td>0.0115</td>
<td>0.0084</td>
<td>0.0107</td>
</tr>
<tr>
<td>Log Likelihood</td>
<td>-63642</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

USA
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Summary of findings
The frailty produces greater uncertainty in the morbidity rate in China whereas it has a greater impact on the recovery and healthy mortality rates in the USA.

### China

<table>
<thead>
<tr>
<th>Incidence</th>
<th>Recovery Rate</th>
<th>Healthy Mortality</th>
<th>Disabled Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="chart1.png" alt="Graph" /></td>
<td><img src="chart2.png" alt="Graph" /></td>
<td><img src="chart3.png" alt="Graph" /></td>
<td><img src="chart4.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

### The USA

<table>
<thead>
<tr>
<th>Incidence</th>
<th>Recovery Rate</th>
<th>Healthy Mortality</th>
<th>Disabled Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="chart5.png" alt="Graph" /></td>
<td><img src="chart6.png" alt="Graph" /></td>
<td><img src="chart7.png" alt="Graph" /></td>
<td><img src="chart8.png" alt="Graph" /></td>
</tr>
</tbody>
</table>
Age onset of disability

- The age most likely onset of disability is delayed by 1 year in 2011 compared with 1998.
- The peak of the disability occurs at an older age for females.
- Less uncertainty for the cohort in the later period.
- Living longer active lives as well as longer lives.
- Sharp decline of years spent in disabled.

![Graphs showing trend of life expectancy](image-url)
Active life expectancy of the total life expectancy

- Ratio of active life expectancy in China faces higher uncertainty than in the USA.
- Trend improvement of the ALE/TLE in China is larger than in the USA.

**Table 3: ALE/TLE in China**

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Static</th>
<th>Time Trend</th>
<th>Frailty</th>
<th>low(95CI)</th>
<th>up(95CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>50</td>
<td>0.96</td>
<td>0.98</td>
<td>0.96</td>
<td>0.91</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>0.94</td>
<td>0.96</td>
<td>0.95</td>
<td>0.87</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>0.93</td>
<td>0.95</td>
<td>0.93</td>
<td>0.88</td>
<td>0.95</td>
</tr>
<tr>
<td>Females</td>
<td>50</td>
<td>0.95</td>
<td>0.97</td>
<td>0.95</td>
<td>0.87</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>0.93</td>
<td>0.95</td>
<td>0.93</td>
<td>0.83</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>0.91</td>
<td>0.93</td>
<td>0.91</td>
<td>0.82</td>
<td>0.94</td>
</tr>
</tbody>
</table>

**Table 4: ALE/TLE in the USA**

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Static</th>
<th>Time Trend</th>
<th>Frailty</th>
<th>low(95CI)</th>
<th>up(95CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>50</td>
<td>0.938</td>
<td>0.936</td>
<td>0.941</td>
<td>0.917</td>
<td>0.967</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>0.911</td>
<td>0.909</td>
<td>0.915</td>
<td>0.896</td>
<td>0.938</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>0.889</td>
<td>0.891</td>
<td>0.892</td>
<td>0.874</td>
<td>0.913</td>
</tr>
<tr>
<td>Females</td>
<td>50</td>
<td>0.901</td>
<td>0.897</td>
<td>0.908</td>
<td>0.866</td>
<td>0.951</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>0.859</td>
<td>0.859</td>
<td>0.867</td>
<td>0.834</td>
<td>0.907</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>0.822</td>
<td>0.825</td>
<td>0.828</td>
<td>0.796</td>
<td>0.861</td>
</tr>
</tbody>
</table>

ALE: Active life expectancy; TLE: Total life expectancy.
Figure 5: Simulated disability-free survival curve for an individual aged 65
Summary: Characteristics in China

- **Factor impact**
  - Residence gap exists in all transition rates.
  - Compression of disability and disabled mortality happens in China.
  - Deterioration of recovery rates shows rather than improvement
  - The role the uncertainty plays (enhance or reduce) on incidence and healthy mortality relates to specific periods.

- **Influence on the life path of individuals**
  - Less uncertainty in the probability of being disabled for the cohort in the later period.
  - Delay of the most likely age onset of disability.
  - Live healthier as well as live longer (Rectangularization of healthy survival curves).
  - Shrinking years spent in disabled.
  - Narrowing gap between disabled and healthy mortality.
Summary: Comparison between China and the USA

Something in common for both countries

- A downward trend for the frailty factor.
- Existence of compression (trend improvement) of incidence of disability.
- Similar role of age and gender for both countries (no gender difference in recovery rates).
- Later occurrence of the peak of the age onset for females.

Something different between China and the USA

- Trend improvement of mortality happens in both countries, but for different groups. It is for the healthy in the USA, while for the disabled in China.
- Significant latent factor impact shows on incidence and healthy mortality in China, compared to on recovery and healthy mortality rates in the US.
- The latent factor produces greater uncertainty in the incidence in China whereas it has a greater impact on the recovery and healthy mortality in the US.
- Ratio of active life expectancy faces higher uncertainty in China than in the USA.
- Disability is expected to occur at older ages in the future due to different reasons. In China it is because of a significant reduction in disability rates. In the US there is expected to be more old-age healthy survivors due to the systematic improvement on mortality rates.
Any suggestion is appreciated . . . Thank You!
Work done so far on China and our contribution

Studies on factor impact in China

- Static
  - Age, Gender and residence impact
    Zhang (2015) and Pan, Sun, and Xue (2015)
  - Dynamic Prevalence of disability over several decades Zheng et al. (2011)
    Time trend Hanewald, Li, and Shao (2017)
Trend improvement in incidence of disability

First introduced by Fries et al. (1984)
- United States (Manton 1988; Reynolds, Crimmins, and Saito 1998; De Leon et al. 1999; Freedman, Martin, and Schoeni 2002; Crimmins and Beltrán-Sánchez 2011; Li, Shao, and Sherris 2017)
- Spain (Sagardui-Villamor et al. 2005)
- UK (Jagger and Clarke 1991; Rickayzen and Walsh 2002)
Necessity of taking uncertainty into account

- Theoretically, complexity of the interplay between innate function decline and environmental factors produces uncertainty in the estimation of health status transitions.
- Practically, Li, Shao, and Sherris (2017) prove the existence of uncertainty in transition rates.

Conclusion
Uncertainty in transition rate rise uncertainty in survival probabilities, life expectancy, and consequently future cost, and provoke the necessity to be taken into account to better capture the risk and allow for stress scenario analysis.

Back
Studies on factor impact on incidence of disability

- **Gender bias**

- **Age effect**
  Guillaume BIESSY (2015): Incidence rate increase exponentially with respect to the age

- **Social, psychosocial environment and historical events**

- **Trend improvement (Existence of compression) of disability**
  First introduced by Fries et al. (1984)
  - United States (Manton 1988; Reynolds, Crimmins, and Saito 1998; De Leon et al. 1999; Freedman, Martin, and Schoeni 2002; Crimmins and Beltrán-Sánchez 2011; Li, Shao, and Sherris 2017)
  - Spain (Sagardui-Villamor et al. 2005)
  - UK (Jagger and Clarke 1991; Rickayzen and Walsh 2002)

- **Uncertainty**
  Li, Shao, and Sherris (2017)