REDDING THE BURDEN OF DISEASE THROUGH TOBACCO TAXES INTERVENTION IN MONGOLIA:
A health impact analysis using a dynamic public health model

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Model parameters

First, demographic data used in this study consist of population size in the baseline year (2018), along with the mortality rate (all causes) and the birth rate. These data and projections of newborns for the period 2015–2045 were obtained from the population projections of the Mongolian Statistical Information Services, assuming a medium level of economic growth. (1)

Second, smoking-prevalence data were obtained from the Mongolian STEPS surveys. The most recent STEPS survey was conducted in 2013.(2) A multi-stage, random cluster sampling method was adopted, targeting a set of 65 country-representative sites (32 urban and 33 rural) in 2013. Randomly selected adults between the ages of 15 and 64 years participated in the survey at each site. The response rate for 2013 was 98%. Data were available in aggregate form by gender and five-year age categories. Three smoking transition rates—start (initiation) rates (never smoker to current smoker), quit (cessation) rates (current smoker to former smoker), and relapse rates (former smoker to current smoker)—were calculated based on the approach developed by van de Kassteele et al. (3). This approach assumes that current smoking behavior will remain constant over time, as supported by the previous STEPS survey (2). Initiation is assumed to occur in the age categories from 15 to 20 years, with cessation and relapse occurring among adults older than 21 years of age.

Third, epidemiological data on smoking-related diseases were collected from the 2018 health-information database administrated by the National Health Center in Mongolia. The International Classification of Diseases-Ten (ICD-10) was applied, and the following diseases were included: ischemic heart diseases (IHD) (I20-I25), stroke (I60-I69; G45), chronic obstructive pulmonary disease (COPD) (J40-J44), oral cavity and pharyngeal cancer (C00-C14), esophageal cancer (C15), and lung cancer (C33-C34). In this dataset, epidemiological data are reported in five-year age categories, with the highest age category stopping at 64 years and older. We used the chronic disease model (DISMOD-II) tool developed by the World Health Organization (WHO) in order to complete missing data on disease-specific prevalence. (4) The DISMOD tool makes it possible to compile an internally consistent epidemiological dataset.(5)(6) Outcome parameters were compared to observed data (where available) and checked by two cancer experts from the National cancer center for face validity.

Relative risk data for the incidence of each disease are presented in Supplementary Table S1. Data were collected from cohort studies investigating RRs for overall and disease-specific mortality associated with tobacco smoking conducted in an Asian setting.(7)(8) We selected studies with at least 11 years of follow-up time and presenting RRs by smoking category (current smoker and former smoker), from an overview of 21 prospective cohort studies in Asia. By assumption the RR for incidence was approximated by the RR for disease specific mortality.
Table S1: Model parameters.

| Variables in the model | Male       | Female     | Reference |
|------------------------|------------|------------|-----------|
| I. Demographic data    |            |            |           |
| Population size by age (0-95) and gender | 1,533,983  | 1,585,952  | (1)(9)    |
| Overall mortality by age (0-95) and gender | 9,812      | 6,538      |           |
| Newborn forecasting (2015-2045) |            |            |           |
| II. Epidemiology data  |            |            |           |
| Incidence              | 10,258     | 15,929     | (10)      |
| Oral cancer (C00-C14)  | 62         | 82         |           |
| Esophageal cancer (C15)| 165        | 161        |           |
| Lung cancer (C34)      | 344        | 97         |           |
| COPD (J40-J44)         | 3,211      | 5,321      |           |
| Stroke (I60-I69, G45)  | 2,697      | 4,975      |           |
| IHD (I20-I25)          | 3,779      | 5,293      |           |
| Deaths                 | 2,981      | 2,496      |           |
| Oral cancer (C00-C14)  | 43         | 30         |           |
| Esophageal cancer (C15)| 151        | 141        |           |
| Lung cancer (C34)      | 279        | 67         |           |
| COPD (J40-J44)         | 86         | 55         |           |
| Stroke (I60-I69, G45)  | 897        | 1,154      |           |
| IHD (I20-I25)          | 1,525      | 1,049      |           |
| Prevalence             | 116,861    | 220,429    | Estimated by the authors using the DISMOD (4) |
| Oral cancer (C00-C14)  | 257        | 869        |           |
| Esophageal cancer (C15)| 123        | 169        |           |
| Lung cancer (C34)      | 585        | 323        |           |
| COPD (J40-J44)         | 49,850     | 88,420     |           |
| Stroke (I60-I69, G45)  | 27,771     | 55,785     |           |
| IHD (I20-I25)          | 38,275     | 74,863     |           |
| III. Risk factor data  |            |            |           |
| Smoking prevalence     |            |            |           |
| Never smoker           | 32.8 (30.2-35.6) | 91.3 (89.1-93.1) | (2)         |
| Current smoker         | 49.2 (54.4-43.4) | 5.3 (8.3-2.5)  |           |
| Former smoker          | 18.0 (15.4-21) | 3.4 (2.6-4.4)  |           |
Table S1 (continued): Model parameters

| Variables in the model                          | Male            | Female           | Reference |
|-----------------------------------------------|-----------------|------------------|-----------|
| **Relative risk for current smokers versus never smokers** |                 |                  |           |
| Oral (C00-C14)                                | 2.02(1.89-2.16) | 2.15(1.88-2.47)  | (7)(8)    |
| Oesophagus (C15)                              | 2.02(1.89-2.16) | 2.15(1.88-2.47)  |           |
| Lung cancer (C34)                             | 4.80 (3.71-6.19) | 3.53 (2.99-4.16) |           |
| COPD (J40-J44)                                | 1.71 (1.51, 1.94) | 2.37 (1.88, 3.00) |           |
| Stroke (I60-I69, G45)                         | 1.47 (1.37, 1.58) | 1.73 (1.50, 2.00) |           |
| IHD (I20-I25)                                 | 1.47 (1.37, 1.58) | 1.73 (1.50, 2.00) |           |
| Death from all-causes                         | 1.70 (1.57-1.84) | 1.71 (1.57-1.86) |           |
| **Relative risk for former smokers versus never smokers** |                 |                  |           |
| Oral cancer (C00-C14)                         | 1.27(1.16-1.36) | 1.62(1.29-2.04)  |           |
| Esophageal cancer (C15)                       | 1.27(1.16-1.36) | 1.62(1.29-2.04)  |           |
| Lung cancer (C34)                             | 4.09 (3.26-5.15) | 3.21 (2.77-3.72) |           |
| COPD (J40-J44)                                | 1.87 (1.62, 2.15) | 1.62 (1.08, 2.41) |           |
| Stroke (I60-I69, G45)                         | 1.24 (1.14, 1.35) | 1.35 (1.11, 1.65) |           |
| IHD (I20-I25)                                 | 1.24 (1.14, 1.35) | 1.35 (1.11, 1.65) |           |
| Death from all-causes                         | 1.59 (1.50-1.68) | 1.66 (1.55-1.79) |           |
| **IV. Price elasticity of demand on smoking prevalence** |                 |                  |           |
| 15-20 years old                               | -0.8 (-0.56 to -0.96) |                   | (11)(12)(13) |
| 21+ years old                                 | -0.4 (-0.2 to -1.00) |                   | (14)(15)    |
Supplement S2: Steps followed to evaluate the health outcomes of tax increases using the DYNAMO-HIA model for Mongolia.

1. Baseline smoking transition rates including initiation rates, quit rates and relapse rates were estimated from observed age specific prevalence rates of never smokers, current smokers, and former smokers. We estimated transition rates between these smoking categories in one-year steps. STEPs survey provides these data on prevalence of smoking categories stratified by gender and one-year age group between 15 to 64 years old. Differences in prevalence of smoking categories at age $x-1$ and at age $x$ was used to estimate the transition rates. This implies assuming stability of smoking behavior in the population over time, and ignoring effects of differences in mortality rates between smoking categories for this calculation. Since it is only for a period of one year, the latter has a relatively small effect. This approach is common in similar modelling exercises to estimate smoking transition rates. (16) (17)
For older age categories above age 64, prevalence of smoking was calculated using the spline interpolation, to supplement incomplete data. (18) This spline fit was used to smooth data until age up to 95 years.

2. Since it is not possible to differentiate between a reduction in initiation rate and an increase in quit rate in the same age group, a reduction in smoking prevalence was assumed to originate from a decrease in initiation rates between age of 15 and up to 20 years old, and an increase in quit rates among adults aged 21 years and older. Meaning that reductions in the prevalence of current smoking among younger people would originate from decreases in initiation rates and among adults (21+) would originate from increases in quit rates.

3. Effects of price changes on smoking prevalence, induced by one-time tax increases were calculated using the price elasticity of demand of cigarettes. However, a smoker can respond in two different ways to an increase in prices. First, he or she can reduce the amounts of cigarettes bought and continue smoking. Alternatively, they can quit smoking. Similarly, never smokers considering smoking initiation could either still start, but smoke less cigarettes, or they might not start at all. For our calculations, we are only interested in the effects of price increases on quitting and on not starting. Effects in terms of a reduction in numbers of cigarettes bought by an individual are ignored, since their health effect is minor. (13)(19) We used an estimate of 50% for the division of effects between reduction of number of cigarettes and complete quitting/not starting. (20)(21) That is, half the effect of the tax increase on the total demand for cigarettes is obtained by a person that completely stop smoking or not start at all.

4. Our scenarios were defined in terms of price increases.
5. Multiplication factors were then calculated for each age category to adjust baseline transition rates until it fits the one-year reduction in smoking prevalence as would be predicted from the price elasticity in combination with the assumption regarding the division of the effect between reduction in numbers of cigarettes and reductions in prevalence of smoking. That is, calibration was applied. Estimated multiplication factors are shown in Table S7 below. For example, the total price elasticity of tobacco is -0.8, meaning that a 10% increase in price leads to an 8% reduction in consumption. By definition, one half of this will result in a decrease in consumption and another one half will result in adjusted smoking prevalence, thus less starting smokers among young people or more quitters among adults. Using this, a 75% increase in price leads to a reduction in current smoking prevalence of 60% (i.e. 0.5*1.6*75%) among youth and 30% (0.5*0.8*75%) among adults. To satisfy this goal, observed initiation rates needed to be reduced by a factor 0.501 among youth, while quit rates needed to increase by a factor 3.09 among adults in the first year. In our sensitivity analysis we varied key parameters in this calculation to their upper and lower limit, namely the price elasticity of demand, and current smoking prevalence, to obtain a range of possible values for these multiplication factors.

6. As a next step, we calculated the reduction in smoking numbers over a period of 3 years, using the decreases in initiation rates between age of 15 and up to 20 years old and increases in quit rates among adults aged 21 years and older. That is, we used our DYNAMO model over a time period of 3 years with the multiplication factors added to our original transition rates (step 1) to carefully estimate the overall effect on smoking prevalence of a tobacco tax increase. Note that this is more precise than many other studies, which directly model smoking prevalence, while our analyses explicitly modelled the actual events that cause changes in prevalence, namely more quitters and less initiation, and used a period of 3 years with adjusted transition rates. (22)(23) This implies that our analyses provide more insight into how the changes in numbers of never, former and current smokers will be distributed over the different age groups, and takes account of any mortality effects during these 3 years.
Table S 2: Estimation of multiplication factors

| Age | Observed smoking prevalence | Estimated baseline transition rates | Effects of tax-increase by 75% on current smoking prevalence | Calibration of observed transition rates |
|-----|-----------------------------|-----------------------------------|-------------------------------------------------------------|----------------------------------------|
|     | Never smoker | Current smoker | Former smoker | Initiation rates | Quit rates | Relapse rates | Current smoking* | Former smoker | Never smoker | Never smoker | Adjusted initiation rates | Multipllication factor |
| 15  | 65.10        | 27.00          | 7.90          | 0.98            | 0.03        | 0            | 10.80          | 7.90          | 81.30          | 82.47          | 0.49 |
| 16  | 64.43        | 27.65          | 7.92          | 2.89            | 0.33        | 0            | 11.06          | 7.92          | 81.02          | 82.06          | 1.45 |
| 17  | 62.57        | 29.45          | 7.98          | 4.63            | 0.34        | 0            | 11.78          | 7.98          | 80.24          | 80.87          | 2.32 |
| 18  | 59.73        | 32.18          | 8.09          | 5.94            | 0.34        | 0            | 12.87          | 8.09          | 79.04          | 79.00          | 2.97 |
| 19  | 56.13        | 35.62          | 8.25          | 7.40            | 0.82        | 0            | 14.25          | 8.25          | 77.50          | 76.65          | 3.71 |
| 20  | 52.00        | 39.54          | 8.46          | 4.71            | 0.53        | 0            | 15.82          | 8.46          | 75.73          | 73.80          | 2.36 |
| Average | | | | | | | | | | 79.14 = 79.14 |
| Age | Observed smoking prevalence | Estimated baseline transition rates | Effects of tax-increase by 75% |
|-----|-----------------------------|-----------------------------------|--------------------------------|
|     | Never smoker | Current smoker | Former smoker | Initiation rates | Quit rates | Relapse rates | Current smoking* | Former smoker | Never smoker | Never smoker |
| 21  | 49.55        | 41.73          | 8.72          | 9.18            | 0.70        | 0.00         | 29.21          | 21.24         | 49.55         | 45.64          | 2.16 |
| 22  | 44.99        | 45.96          | 9.05          | 9.78            | 0.87        | 0.00         | 32.17          | 22.83         | 44.99         | 49.50          | 2.69 |
| 23  | 40.55        | 50.01          | 9.43          | 10.19           | 0.98        | 0.00         | 35.01          | 24.44         | 40.55         | 52.76          | 3.03 |
| 24  | 36.45        | 53.67          | 9.88          | 9.77            | 0.95        | 0.00         | 37.57          | 25.98         | 36.45         | 55.12          | 2.94 |
| ... | ...           | ...            | ...           | ...             | ...         | ...           | ...            | ...           | ...           | ...           | ... |
| 61  | 30.90        | 46.71          | 22.39         | 0.42            | 0.22        | 0.00         | 32.69          | 36.40         | 30.90         | 26.66          | 0.68 |
| 62  | 30.77        | 46.73          | 22.49         | 0.64            | 0.33        | 0.00         | 32.71          | 36.52         | 30.77         | 26.68          | 1.02 |
| 63  | 30.57        | 46.78          | 22.65         | 0.85            | 0.43        | 0.00         | 32.74          | 36.68         | 30.57         | 26.67          | 1.34 |
| 64  | 30.31        | 46.83          | 22.85         | 1.04            | 0.53        | 0.00         | 32.78          | 36.90         | 30.31         | 26.62          | 1.63 |
| Average | | | | | | | | | | 36.01 = 36.02 |
7. The resulting prevalence was stored (age and gender specific) and used as a starting point for the long-term calculations. That is, a new DYNAMO-HIA model analysis was performed with a 30-year time horizon, using as initial prevalence the outcomes of step 6 and assuming transition rates at baseline values (as calculated in step 1).
Steps 7 and 8 could have been combined into one calculation step if we had been able to work with smoking transition rates that were different in years 1-3 from years 4 and over in DYNAMO-HIA. However, DYNAMO-HIA works with a single set of input data. That is, the model will not allow to perform a lifetime analysis that features a switch in transition rates after 3 years. Since we consider it is not realistic that a one-time price increase will lead to lifetime effects on transition rates, we have used a period of 3 years for the effect of the price increase and stopped to evaluate numbers in each smoking category by age after 3 years (step 7). We then used this new prevalence, as a starting point for a new lifetime evaluation with DYNAMO-HIA, using original transition rates, to find the long-term results of the taxation policy (step 8).

8. The intervention effects on population health were then estimated by summarizing quality-adjusted life year gains (QALYs) from smoking-related diseases morbidity and mortality over a 30-years’ time horizon and discounting them at a rate of 3% per year. That is, net present values were calculated, using the following formula:

\[ NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t} \]

where:
- \( R_t \)=Total QALYs during a single period \( t \)
- \( i \)=Discount rate
- \( t \)=Number of years

Table S 3: Intervention scenarios, (all prices in Int $, 2018)

| Components                          | Base year In 2018 | Intervention scenarios |
|-------------------------------------|-------------------|------------------------|
|                                     |                   | 25% price increase     | 75% price increase |
| Retail price of cigarette (most sold brand) | 2.77              | 3.46                   | 4.85               |
| Price before value-added tax (VAT)   | 2.54              | 3.17                   | 4.44               |
| Excise tax (ET)                      | 1.05              | 1.68                   | 2.95               |
| ET as % of price                     | 38.0              | 48.7                   | 60.9               |
| Pretax price                         | 1.49              | 1.49                   | 1.49               |
Table S4: Actual excise taxes by year in Mongolia

| Quantity                  | Currency          | Amount of excise tax | 2017 | 2018 | 2019 | 2020 and later on |
|---------------------------|-------------------|----------------------|------|------|------|-------------------|
| 20-cigarette per pack    | In MNT            | 696                  | 766  | 800  | 836  |
| Int $ (2018)              |                   | 0.96                 | 1.05 | 1.10 | 1.15 |

Source: www.legal.mn/434/(24); MNT=Mongolian tugrik

Table S5: Effect of price changes on smoking prevalence

| Scenarios                              | 75% price increase | 25% increase | Assumption/references                                                                 |
|----------------------------------------|--------------------|---------------|--------------------------------------------------------------------------------------|
| Age group                              | 15-20              | 21+           | Most smokers starts early in life. (13)(25)                                           |
| Total price elasticity of demand       | -1.6               | -0.8          | An increase in price of 10% will lead to a reduction in cigarette consumption around 8% for adults aged 21+. (26)(27)(28) |
|                                        |                    |               | Young people are more price sensitive than the adults, resulting in a price elasticity that is circa twice that of adults. (11)(29)(30) |
| Smoking participation price elasticity | -0.8               | -0.4          | Half of the effect is due to the reduction in smoking prevalence and another half due to the reduction in smoking intensity. (13)(31) |
| Reduction in smoking prevalence        | -60%               | -30%          | A 75% increase in price leads to a 60% (i.e. 0.8*75%) reduction in smoking prevalence among young people, and to a 30% reduction (i.e. 0.4*75%) among adults. |
Table S 6: Estimated adjustment factors for baseline initiation and quit rates, for three levels of price elasticity (point estimates, lower and upper confidence limits).

| Gender | Age group | Baseline smoking-transition rates | 75% price increase | 25% price increase |
|--------|-----------|-----------------------------------|--------------------|--------------------|
|        |           |                                   | Price elasticity    | Price elasticity    |
|        |           | Mean | Lower | Upper | Mean | Lower | Upper |
| Male   | 15-20     | Initiation rate                   |                    |                    |
|        |           | Mean 0.50 | 0.65 | 0.41 | Mean 0.87 | 0.88 | 0.84 |
|        |           | Lower 0.65 |        |      | Lower 0.88 | 0.79 |      |
|        |           | Upper 0.39 |        |      | Upper      |      |      |
|        | 21+       | Quit rate                          |                    |                    |
|        |           | Mean 3.09 | 1.62 | 3.93 | Mean 1.69 | 1.28 | 1.84 |
|        |           | Lower 2.68 |        |      | Lower 2.21 |      |      |
|        |           | Upper 4.17 |        |      | Upper 2.11 |      |      |
| Female | 15-20     | Initiation rate                   |                    |                    |
|        |           | Mean 0.68 | 0.78 | 0.58 | Mean 0.90 | 0.93 | 0.87 |
|        |           | Lower 0.88 |        |      | Lower 0.96 | 0.79 |      |
|        |           | Upper 0.39 |        |      | Upper      |      |      |
|        | 21+       | Quit rate                          |                    |                    |
|        |           | Mean 3.32 | 2.01 | 4.15 | Mean 1.85 | 1.57 | 1.96 |
|        |           | Lower 4.35 |        |      | Lower 3.40 |      |      |
|        |           | Upper 3.84 |        |      | Upper 1.40 |      |      |
Table S 7: Cumulative intervention effects in terms of QALYs gains for a 75% price-increase, stratified by 10 year time intervals. (in thousands)

| Disease name | Time horizon | Male          | Female         | Both           |
|--------------|--------------|---------------|----------------|----------------|
|              |              | Mean (95% UR) | Mean (95% UR)  | Mean (95% UR)  |
| Overall      | 10 years     | 8.9 (7.64–10.17) | 3.9 (0–4.49)   | 12.9 (7.64–14.66) |
|              | 20 years     | 42.9 (38.4–47.05) | 14.2 (0–16.2)  | 57.1 (38.4–63.24) |
|              | 30 years     | 106.1 (97.35–114.61) | 31.6 (0–36.08) | 137.7 (97.35–150.7) |
| Oral cancer  | 10 years     | 1.5 (1.32–1.75)  | 0.7 (0–0.8)    | 2.2 (1.32–2.55)  |
|              | 20 years     | 7.3 (6.38–8.06)  | 2.5 (0–2.86)   | 9.8 (6.38–10.92) |
|              | 30 years     | 18.1 (16.57–19.51) | 5.6 (0–6.38)   | 23.6 (16.57–25.9) |
| Esophagus cancer | 10 years | 1.5 (1.32–1.75)  | 0.7 (0–0.8)    | 2.2 (1.32–2.55)  |
|              | 20 years     | 7.3 (6.58–8.06)  | 2.5 (0–2.86)   | 9.9 (6.58–10.92) |
|              | 30 years     | 18.1 (16.59–19.54) | 5.6 (0–6.39)   | 23.7 (16.59–25.93) |
| Lung cancer  | 10 years     | 1.5 (1.31–1.73)  | 0.7 (0–0.8)    | 2.2 (1.31–2.53)  |
|              | 20 years     | 7.2 (6.49–7.94)  | 2.5 (0–2.86)   | 9.7 (6.49–10.8)  |
|              | 30 years     | 17.8 (16.3–19.2) | 5.6 (0–6.37)   | 23.3 (16.3–25.57) |
| IHD          | 10 years     | 1.3 (1.15–1.55)  | 0.6 (0–0.7)    | 2.0 (1.15–2.25)  |
|              | 20 years     | 6.6 (5.86–7.25)  | 2.3 (0–2.59)   | 8.8 (5.86–9.84)  |
|              | 30 years     | 16.6 (15.24–18.02) | 5.1 (0–5.81)   | 21.7 (15.24–23.83) |
| Stroke       | 10 years     | 1.5 (1.26–1.69)  | 0.7 (0–0.78)   | 2.2 (1.26–2.47)  |
|              | 20 years     | 7.1 (6.37–7.82)  | 2.5 (0–2.83)   | 9.6 (6.37–10.65) |
|              | 30 years     | 17.7 (16.21–19.11) | 5.6 (0–6.35)   | 23.2 (16.21–25.46) |
| COPD         | 10 years     | 1.5 (1.29–1.7)   | 0.5 (0–0.61)   | 2.0 (1.29–2.31)  |
|              | 20 years     | 7.2 (6.51–7.92)  | 1.9 (0–2.18)   | 9.2 (6.51–10.11) |
|              | 30 years     | 17.9 (16.43–19.23) | 4.2 (0–4.78)   | 22.1 (16.43–24.01) |
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