Productivity burden of smoking in Australia: a life table modelling study

Alice J Owen, Salsabil B Maulida, Ella Zomer, Danny Liew

ABSTRACT

Objectives This study aimed to examine the impact of smoking on productivity in Australia, in terms of years of life lost, quality-adjusted life years (QALYs) lost and the novel measure of productivity-adjusted life years (PALYs) lost.

Methods Life table modelling using contemporary Australian data simulated follow-up of current smokers aged 20–69 years until age 70 years. Excess mortality, health-related quality of life decrements and relative reduction in productivity attributable to smoking were sourced from published data. The gross domestic product (GDP) per equivalent full-time (EFT) worker in Australia in 2016 was used to estimate the cost of productivity loss attributable to smoking at a population level.

Results At present, approximately 2.5 million Australians (17.4%) aged between 20 and 69 years are smokers. Assuming follow-up of this population until the age of 70 years, more than 3.1 million years of life would be lost to smoking, as well as 6.0 million QALYs and 2.5 million PALYs. This equates to 4.2% of years of life, 9.4% QALYs and 6.0% PALYs lost among Australian working-age smokers. At an individual level, this is equivalent to 1.2 years of life, 2.4 QALYs and 1.0 PALY lost per smoker. Assuming (conservatively) that each PALY in Australia is equivalent to $A1.57 billion (GDP per EFT worker in 2016), the economic impact of lost productivity would amount to $A388 billion.

Conclusions This study highlights the potential health and productivity gains that may be achieved from further tobacco control measures in Australia via application of PALYs, which are a novel, and readily estimable, measure of the impact of health and health risk factors on work productivity.

INTRODUCTION

The Global Burden of Disease study demonstrated that smoking continues to exert a significant mortality burden, with worldwide smoking-attributable deaths increasing by 20% since 1990. In Australia, following adoption of a series of tobacco control measures, age-standardised smoking prevalence decreased from 30.8% to 16.8% from 1980 to 2012. However, given population growth, this still represents a substantial number of smokers and a large burden of tobacco-related disease, with >15 000 Australians projected to succumb to premature tobacco-related death each year.

The healthcare costs of tobacco-related morbidity and mortality (ie, the costs of treating smoking-related illnesses in those who smoke) have been well described, with around 15% of healthcare expenditure attributed to smoking in high-income countries. However, these direct costs represent only a proportion of the adverse economic impact of tobacco smoking. Indirect costs include second-hand smoke exposure, costs to employers arising from absenteeism and lost productivity due to smoking among their workforce, welfare benefits associated with supporting those with chronic smoking-related illness and smoking-attributable fires. Less readily quantifiable societal burdens include the social and emotional impact of smoking-related mortality and morbidity on family and loved ones. Of the indirect costs, productivity losses are substantial, but often of lower profile. In Australia in the financial year 2004/2005, it was estimated that the productivity losses associated with smoking was $A8 billion, which far outweighed the $A1.8 billion in direct healthcare costs of smoking.

Price-based tobacco control measures (such as tobacco taxes) have been shown to be the most effective method for reducing tobacco consumption. However, tobacco consumption also confers economic benefits, including income generated as a result of the production and consumption of tobacco and tobacco taxes accrued by governments. These counterbalancing financial issues are often raised when governments are considering tobacco control measures.

In order to provide a clearer understanding of the macro-economic impact of productivity loss due to smoking, we undertook a study that uses a novel measure developed by our group, productivity-adjusted life years (PALYs), to examine the productivity burden of smoking in a contemporary Australian setting.

METHODS

We used life table modelling and decision analysis to examine the impact of smoking on years of life, quality-adjusted life years (QALYs) and PALYs lived among Australians of working age. PALYs are a construct similar to QALYs, but with years of life lived penalised for time spent with reduced work productivity (instead of reduced quality of life) as a result of ill health. Akin to utilities that quantify quality of life, ‘productivity indices’ represent the productivity of an individual in proportional terms, ranging from 1.0 (100% productive) to 0 (completely non-productive). Productivity indices may change, for example, with age and/or ill health.

Life tables were constructed using age-specific and sex-specific rates of mortality for smoking and non-smoking adults aged 20–69 years, based on the 2016 Australian population (see online supplementary appendix 1 and table I). The cohorts were followed until death or age 70 years. The 20–69 years age range was chosen to reflect the ages where people are commonly engaged in paid work.
smoking. This study found that smokers missed more days at work (absenteeism) (6.7 vs 4.4 days/year) and experienced more unproductive days (presenteeism) (3.2 vs 1.8 days/year) compared with non-smokers. As annual working days varies by age and sex, Australian workforce participation data were used to calculate sex-specific weighted-average maximum working days in a year among Australians aged 20–69 years. The age-specific and sex-specific productivity indices were then calculated by applying productivity penalties of 0.957 for non-smokers and 0.932 for smokers (calculated from Bunn et al., as above) to the EFT, equivalent full time.

### Data sources

Age-specific and sex-specific mortality rates for single-year age bands were obtained from the Australian General Record of Incidence of Mortality data for 2015. Smoking prevalence data were drawn from the Australian National Health Survey 2014–2015. Probabilities of death for smokers and non-smokers were calculated from mortality risk in the wider population and population-attributable risk percentage (proportion of all deaths occurring in a population that is attributable to smoking) reported by Peto et al., and extrapolated above and below the age of 35 years using exponential equations for male and female smokers and non-smokers. The sex-specific and age-specific probabilities of death for smokers and non-smokers are listed in online supplementary appendix 1.

For the modelling of QALYs, we derived utility decrements due to smoking from a 2010 US study examining trends in health-related quality of life (assessed using the EuroQol 5D (EQ-5D) quality of life tool) associated with smoking by Jia and Lubetkin. Productivity decrements due to smoking were estimated from a study by Bunn et al examining productivity loss due to smoking. Analyses were then repeated with the smoking cohort assumed to be non-smokers, and years of life, QALYs and PALYs were recalculated. The differences in these measures between the two cohort simulations represented the years of life, QALYs and PALYs lost to smoking.

Within each of the smoking and non-smoking cohorts, we created separate life tables with 1 year cycles for 20 sex-and-age subcohorts, with age being stratified into ten 5-year age bands: 20–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64 and 65–69 years. The starting age in each subcohort was assumed as the mid-point of the age group (eg, 22 years for age group 20–24 years, 27 years for age group 25–29 years).

For each sex-age cohort, specific mortality rates (by age, sex and smoking status) were applied, as well as smoking-related utilities derived from health-related quality of life measures and productivity indices calculated from previously reported rates of absenteeism and presenteeism in smoking compared with non-smoking workers.

Analyses assuming a 10%, 25%, 50%, 75% and 90% reduction in current smoking prevalence rates were also undertaken.

### RESULTS

#### Excess mortality burden attributable to smoking

Among Australians currently aged 20–69 years who smoke and are followed up until age 70 years, the estimated number of deaths attributable to their smoking was 277261 in males and 129277 in females, equating to 61.7% and 61.8% of the predicted number of total deaths among smoking males and smoking females, respectively (table 2). The 406538 excess smoking-attributable deaths represented 23.1% of all deaths predicted to occur among the whole population aged 25–69 years, if followed to age 70 years.

If smoking prevalence in the working age population was half of what it currently is, 203 629 smoking-related deaths could be averted in the working age population if followed to age 70 years (table 6).

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**Table 1 Modelled population**

| Age group (years) | Males | | | | | Females | | | |
|-------------------|-------|-------------------------------|-------------------|-------|-------------------------------|-------------------|-------|-------------------------------|-------------------|
|                   | n*    | Smoking prevalence† | EFT %‡ |       | n*    | Smoking prevalence† | EFT%‡ |
| 20–24             | 851 818 | 0.162 | 54.1 |       | 807 634 | 0.173 | 48.7 |
| 25–29             | 885 390 | 0.255 | 79.7 |       | 873 715 | 0.142 | 57.2 |
| 30–34             | 876 875 | 0.255 | 79.7 |       | 874 000 | 0.142 | 57.2 |
| 35–39             | 785 670 | 0.222 | 84.3 |       | 790 262 | 0.141 | 55.3 |
| 40–44             | 819 943 | 0.222 | 84.3 |       | 835 414 | 0.141 | 55.3 |
| 45–49             | 774 379 | 0.207 | 78.0 |       | 789 310 | 0.172 | 56.9 |
| 50–54             | 769 307 | 0.207 | 78.0 |       | 788 657 | 0.172 | 56.9 |
| 55–59             | 714 584 | 0.183 | 68.2 |       | 736 359 | 0.129 | 49.2 |
| 60–64             | 632 862 | 0.183 | 52.2 |       | 653 546 | 0.129 | 33.6 |
| 65–69             | 570 582 | 0.111 | 33.6 |       | 582 977 | 0.069 | 17.7 |
| Total             | 7 681 410 |       |       |       | 6 924 240 |       |       |

*Australian population at 2015.
†Smoking prevalence data from the Australian National Health Survey 2014–2015.
‡Percentage of total EFT workers from Australian workforce participation data.
§Australian population at 2015.

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References

1. Owen AJ, et al. Tobacco Control 2019; 28:297–304. doi:10.1136/tobaccocontrol-2018-054263
Years of life lost to smoking
The estimated years of life lived by the smoking and (hypothetically) non-smoking cohorts are summarised in table 3. Overall, it was estimated that smoking at current prevalence reduced the number of years of life lived by 2 227 326 years among males and 914 602 years in females. The total reduction in 3 141 928 years of life lived equated to a 4.2% loss among smokers, and represented a 0.9% loss among the whole population. This equated to 1.2 years of life lost per smoker.

Quality-adjusted life years lost to smoking
The estimated QALYs lived by the smoking and (hypothetically) non-smoking cohorts are summarised in table 4. Overall, it was estimated that smoking reduced the number of QALYs by 3 849 150 among males and 2 179 623 among females, equating to 2.4 QALYs lost per male smoker and 2.3 QALYs lost per female smoker over the remainder of their working lifetime. The total reduction in 6 028 773 QALYs equated to a 9.4% loss among smokers, and a 2.1% loss among the whole population.

Productivity-adjusted life years lost to smoking
The estimated PALYs lived by the population are summarised in table 5. Overall, it was estimated that smoking reduced the number of PALYs by 1 711 214 among males and 702 931 among females. The total reduction in 2 475 144 PALYs equated to a 56.0% loss among smokers (with a range of 5.4%–7.1% when upper and lower absenteeism estimates were applied to the model), and a 1.3% loss among the whole population as well as 1.0 PALY lost per smoker, calculated by dividing the total PALYs lost among smokers by the number of smokers in the population at the start of the modelled period.

As with years of life and QALYs, more PALYs were lost by males, because of their higher smoking prevalence, as well as by people of middle-age, because of the combination of greater smoking prevalence and proportion of people working in these age groups. In women, the highest proportional loss of PALYs occurred in those aged 45–64 years (table 5). The highest smoking prevalence among women was observed in the 45–54 years age group (table 1), and the potential years of productive life gained through prevention targeting this group might also warrant focus.

Assuming the cost of each PALY is $A157 000, the total cost of productivity loss attributable to smoking was estimated to be $A388 billion over the working life of the current Australian population. If a 50% reduction in current smoking prevalence could be achieved, an additional 1 237 572 PALYs, and $A194 billion in GDP, could potentially be saved (table 6), but any savings would need to be offset by the cost of the prevention programme. Even more modest reductions in smoking prevalence (10%) could confer substantial lifetime productivity gains of >$A38 billion (table 6).
The findings of our study highlight the substantial impact of smoking on health and productivity in the Australian population. Among Australians currently aged 20–69 years who are followed up to age 70 years, smoking was predicted to result in an excess of over 400,000 deaths, with a loss of >3 million years of life over the productive working age of current Australian smokers, and a 6% loss of PALYs, equating to 5.38 million lost in GDP.

Productivity losses accrued from a combination of premature mortality, morbidity-associated work absences (absenteeism) and reductions in productive capacity while at work (presenteeism). In our analyses, males and females who smoke were estimated to experience an almost threefold increase in the risk of death compared with people who do not smoke. This result is comparable to a study in 2015 on male British doctors by Doll et al suggested that male smokers died on average 10 years earlier compared with non-smokers. A study in Chinese adults estimated smokers at age 35 years lost around 2.5 years of life when compared with people who never smoked, while in a Norwegian population it was estimated that 1.4–2.7 years of life were lost in heavy smokers aged 40–70 years. A recent study modelling average life expectancy in the Australian population by Mannan et al found that reducing the prevalence of smoking among Australian smokers to 10% would increase the life expectancy by 0.4–2 years for males and 0.7–2 years for females.

Our study estimated that smoking would cause a loss of over 2.4 million PALYs among Australians currently aged 20–69 years who smoke, if followed up until age 70 years. This equated to 1.0 PALY lost per smoker. This compares with the loss of 1.4 PALYs per working age person with diabetes over a similar time horizon. The differences are attributable to a higher prevalence of diabetes than smoking and a greater reduction in productivity conferred by diabetes than smoking. Of course, this does not mean greater priority should be given to prevention of diabetes, which is more difficult to achieve than smoking.

The loss of productivity, measured in terms of PALYs, among the working population has economic implications. Our study is the first to examine this cost in terms of life lost to smoking was also higher among younger age groups, because of higher smoking prevalence (particularly among men) and follow-up time within the modelled period. Smoking is well known to decrease life expectancy. A study capturing 50 years of observation of male British doctors by Doll et al suggested that male smokers died on average 10 years earlier compared with non-smokers.

The costs of smoking are highest among Australian smokers aged 20–24 years, where the average loss of 3.98 years of life is almost two-thirds of the national average. Of the estimated 1.0 PALY lost per smoker, 0.4 PALY were lost due to smoking-related mortality alone, with a further 0.6 PALY lost due to smoking-related morbidity and productivity losses. In contrast, smokers aged 65–69 years lost 0.30 PALY of life due to smoking, compared with 0.42 PALY among smokers aged 20–24 years. Smoking reduced life expectancy by 0.6 PALY for smokers aged 20–24 years, compared with 0.4 PALY for smokers aged 65–69 years.

In our study, the years of life lost was lower among females, due to a lower prevalence of smoking. As expected, years of life lost to smoking was also higher among younger age groups, because of higher smoking prevalence (particularly among men) and follow-up time within the modelled period.

Table 3: Years of life (YOL) lived by working age Australians

| Age group | YOL lived by smoking status quo | Total population YOL lived status quo | YOL lost to smoking | % YOL lost due to smoking status quo | % YOL lost with 50% reduction in smoking |
|-----------|-------------------------------|--------------------------------------|---------------------|------------------------------------|----------------------------------------|
| Males (years) |                               |                                      |                     |                                    |                                        |
| 20–24    | 6 145 373                     | 39 307 975                           | 265 535             | 4.1                                | 2.1                                    |
| 25–29    | 8 950 587                     | 36 344 717                           | 425 928             | 4.5                                | 2.3                                    |
| 30–34    | 7 780 771                     | 31 707 597                           | 408 948             | 5.0                                | 2.6                                    |
| 35–39    | 5 237 777                     | 24 645 072                           | 300 038             | 5.4                                | 2.8                                    |
| 40–44    | 4 614 212                     | 21 773 435                           | 282 121             | 5.8                                | 3.0                                    |
| 45–49    | 3 324 052                     | 16 881 433                           | 214 886             | 6.1                                | 3.1                                    |
| 50–54    | 2 582 922                     | 13 133 827                           | 171 223             | 6.2                                | 3.2                                    |
| 55–59    | 1 537 322                     | 8 852 002                            | 101 095             | 6.2                                | 3.2                                    |
| 60–64    | 849 051                       | 4 865 887                            | 50 682              | 5.6                                | 2.9                                    |
| 65–69    | 180 374                       | 1 680 018                            | 6870                | 3.7                                | 1.9                                    |
| All males | 41 202 441                    | 199 191 963                          | 2 227 326           | 5.1                                | 2.6                                    |
| Females (years) |                               |                                      |                     |                                    |                                        |
| 20–24    | 6 409 464                     | 37 795 327                           | 156 139             | 2.4                                | 1.2                                    |
| 25–29    | 5 078 772                     | 36 593 269                           | 136 914             | 2.6                                | 1.3                                    |
| 30–34    | 4 470 811                     | 32 294 539                           | 134 049             | 2.9                                | 1.5                                    |
| 35–39    | 3 473 004                     | 25 322 584                           | 113 481             | 3.2                                | 1.6                                    |
| 40–44    | 3 106 410                     | 22 683 205                           | 107 010             | 3.3                                | 1.7                                    |
| 45–49    | 2 933 165                     | 17 567 640                           | 106 847             | 3.5                                | 1.8                                    |
| 50–54    | 2 290 447                     | 13 741 266                           | 88 225              | 3.7                                | 1.9                                    |
| 55–59    | 1 160 534                     | 9 302 586                            | 45 350              | 3.8                                | 1.9                                    |
| 60–64    | 638 150                       | 5 672 105                            | 23 559              | 3.6                                | 1.8                                    |
| 65–69    | 116 448                       | 1 728 512                            | 30 282              | 2.5                                | 1.3                                    |
| All females | 29 677 206                    | 202 701 034                          | 9 146 02           | 3.0                                | 1.5                                    |
| Total    | 70 879 647                    | 401 892 998                          | 3 141 928           | 4.2                                | 2.2                                    |

DISCUSSION

The findings of our study highlight the substantial impact of smoking on health and productivity in the Australian population. Among Australians currently aged 20–69 years who are followed up to age 70 years, smoking was predicted to result in an excess of over 400,000 deaths, with a loss of >3 million years of life over the productive working age of current Australian smokers, and a 6% loss of PALYs, equating to 5.38 million lost in GDP. Productivity losses accrued from a combination of premature mortality, morbidity-associated work absences (absenteeism) and reductions in productive capacity while at work (presenteeism). In our analyses, males and females who smoke were estimated to experience an almost threefold increase in the risk of death compared with people who do not smoke. This result is comparable to a study in 2015 on male British doctors by Doll et al suggested that male smokers died on average 10 years earlier compared with non-smokers. A study in Chinese adults estimated smokers at age 35 years lost around 2.5 years of life when compared with people who never smoked, while in a Norwegian population it was estimated that 1.4–2.7 years of life were lost in heavy smokers aged 40–70 years. A recent study modelling average life expectancy in the Australian population by Mannan et al found that reducing the prevalence of smoking among Australian smokers to 10% would increase the life expectancy by 0.4–2 years for males and 0.7–2 years for females.

Our study estimated that smoking would cause a loss of over 2.4 million PALYs among Australians currently aged 20–69 years who smoke, if followed up until age 70 years. This equated to 1.0 PALY lost per smoker. This compares with the loss of 1.4 PALYs per working age person with diabetes over a similar time horizon. The differences are attributable to a higher prevalence of diabetes than smoking and a greater reduction in productivity conferred by diabetes than smoking. Of course, this does not mean greater priority should be given to prevention of diabetes, which is more difficult to achieve given its multiplicity of risk factors, chief among which is genetic.

The loss of productivity, measured in terms of PALYs, among the working population has economic implications. Our study is the first to examine this cost in terms...
of PALYs, but previous studies have estimated the cost of productivity loss due to smoking via other means. In a study on the Australian population by Collins and Lapsley, it was estimated that smoking caused a loss of $A4.9 billion due to presenteeism (0.5% of GDP) and $A779 million due to absenteeism (0.08% of GDP) in the single financial year of 2004/2005. In 2000, Lightwood et al reported that the total economic costs of smoking, including productivity losses, amounted to 2.1%–3.4% of GDP in Australia. A study in Thailand reported that the economic burden of smoking was 0.8% of country GDP, while the revenue from tobacco industry only contributed to 0.5% of the total GDP. The results of our study are not directly comparable to those of other studies because of the differences in evaluation time horizons, which varied from 1 to 50 years in our study (depending on the age of the smokers), and which for other studies was limited to a single year. We had also adopted a simple ‘top-down’ approach to allocating total GDP to EFT worker. Nonetheless, our conclusion is the same as that of the other studies; that smoking imposes a large economic burden on productivity.

It is therefore clear that prevention of smoking is important from an economic standpoint. The high indirect costs of smoking suggest that it would be better for policy makers to consider the amount of money spent on prevention strategies as an ‘investment’ rather than as an ‘expenditure’.

Our study did not address the issue of smoking cessation. Rather, it sought to provide a conceptual illustration of the productivity losses due to smoking by assuming hypothetically that it did not exist, that is, smoking was not taken up in the first place. It should be acknowledged that this is a hypothetical scenario, and in reality, smoking cessation interventions as well as interventions or policy settings dissuading smoking uptake, would be required to aim for the productivity gains modelled herein, even those projected from more modest reductions in smoking prevalence. Smoking cessation is beneficial to productivity. A recent study in Japan suggested that smoking cessation improved productivity at work, with the productivity and associated costs of former smokers being similar to those who never smoked. This finding is supported by the findings of Baker et al, who found no significant difference between former and never smokers in term of productivity loss in China, the US and Europe. A 19-year follow-up study among males in Finland by Kiiskinen et al also stated that quitting smoking could avert almost 60% of losses due to the direct and indirect costs of smoking.

Our study is the first to examine the impact of smoking on productivity in terms of PALYs, a novel and informative measure. Our method uses readily available data to estimate the macroeconomic productivity impact of smoking in a methodologically accessible manner, which could be applied in a variety of other country settings or risk/disease burdens. Further research using PALYs provides the opportunity to compare the effects of different tobacco control measures across various age, sex and employment settings, which can inform the targeting of interventions. In addition, application of this method across countries would provide a greater

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**Table 4 The impact of smoking on QALYs**

| Age group | QALYs smokers status quo | QALYs non-smokers | QALYs lost to smoking | QALYs lost per smoker | % QALYs lost | QALYs gained with 50% reduction in smoking prevalence |
|-----------|-------------------------|------------------|----------------------|---------------------|-------------|-----------------------------------------------------|
| Males (years) |                                      |                  |                      |                     |             |                                                      |
| 20–24     | 5 151 031               | 29 339 229       | 520 753              | 3.8                 | 9.2         | 260 377                                             |
| 25–29     | 7 453 501               | 24 098 836       | 795 094              | 3.5                 | 9.6         | 397 547                                             |
| 30–34     | 6 444 321               | 20 939 735       | 722 970              | 3.2                 | 10.1        | 361 485                                             |
| 35–39     | 4 306 803               | 16 868 553       | 506 589              | 2.9                 | 10.5        | 253 294                                             |
| 40–44     | 3 755 848               | 14 774 434       | 459 993              | 2.5                 | 10.9        | 229 997                                             |
| 45–49     | 2 682 939               | 11 578 168       | 339 357              | 2.1                 | 11.2        | 169 679                                             |
| 50–54     | 2 083 241               | 8 992 229        | 264 037              | 1.7                 | 11.2        | 132 018                                             |
| 55–59     | 1 238 278               | 6 211 331        | 153 000              | 1.2                 | 11.0        | 76 500                                              |
| 60–64     | 681 174                 | 3 382 554        | 75 675               | 0.7                 | 10.0        | 37 938                                              |
| 65–69     | 14 111 914              | 1 246 204        | 114 898              | 0.2                 | 7.4         | 57 41                                               |
| All males | 33 941 864              | 137 431 273      | 3 849 150            | 2.4                 | 10.2        | 1 924 575                                           |
| Females (years) |                                      |                  |                      |                     |             |                                                      |
| 20–24     | 5 367 135               | 27 756 781       | 439 301              | 3.1                 | 7.6         | 219 651                                             |
| 25–29     | 4 225 511               | 27 713 660       | 361 132              | 2.9                 | 7.9         | 180 566                                             |
| 30–34     | 3 699 805               | 24 341 905       | 328 808              | 2.6                 | 8.2         | 164 404                                             |
| 35–39     | 2 853 714               | 18 985 742       | 262 688              | 2.4                 | 8.4         | 131 344                                             |
| 40–44     | 2 527 472               | 16 652 454       | 238 764              | 2.0                 | 8.6         | 119 382                                             |
| 45–49     | 2 367 114               | 12 496 402       | 228 757              | 1.7                 | 8.8         | 114 378                                             |
| 50–54     | 1 847 075               | 9 757 885        | 179 925              | 1.3                 | 8.9         | 89 963                                              |
| 55–59     | 934 645                 | 6 913 003        | 89 209               | 0.9                 | 8.7         | 44 605                                              |
| 60–64     | 512 375                 | 4 238 671        | 44 796               | 0.5                 | 8.0         | 22 398                                              |
| 65–69     | 93 042                  | 1 339 625        | 62 424               | 0.2                 | 6.3         | 31 21                                               |
| All females | 24 427 888             | 150 396 127      | 2 179 623            | 2.3                 | 8.2         | 1 089 812                                           |
| Total     | 58 369 753              | 287 827 400      | 6 028 773            | 2.4                 | 9.4         | 3 014 386                                            |

Data are n or % of QALY lost at current smoking prevalence, or potential QALY gained (n) with a hypothetical 50% reduction in smoking prevalence across all ages and sex. QALY, quality-adjusted life years.
understanding of the regional and global indirect costs of smoking, and the potential productivity gains from tobacco control. Quantifying burden of disease in terms of PALYs can inform resource allocation and decision making for public and workplace health strategies, and may assist in leveraging employer engagement with tobacco control programs.

PALYs are like QALYs because they ‘penalise’ time spent alive by people affected by a disease or condition, and do so in the same manner—by proportionally adjusting time according to the relative extent to which productivity (PALYs) or quality of life (QALYs) is affected by that disease or condition. QALYs have limitations that stem from their attempting to quantify the highly subjective nature of quality of life and how much people value it,29–31 but despite these limitations, they remain important measures of burden of disease that help inform healthcare planning. Furthermore, healthcare decision making does not rely on QALYs alone; many other factors need to be taken into consideration. As discussed, we feel that the impact of ill health on productivity should be among these factors, and PALYs offer a convenient method for measuring this. One advantage that PALYs have over QALYs is that the measurement and concept of productivity loss is much more objective than the measurement and concept of quality of life.

Several limitations of our study warrant mention. First, our analyses did not take into account healthcare costs devoted to managing smoking-related ill health, which were estimated to be $A318 million in the year 2004/2005 (offset for savings accrued through premature mortality).6 Furthermore, potential gains from reductions in passive smoking-related mortality and morbidity, and productivity losses associated with family members caring for those with disabling smoking-related morbidity were also excluded. On the other hand, we did not consider the economic activity associated with production and sale of tobacco products, all of which contribute to GDP nor government revenue generated from tobacco taxes.

Second, life table modelling is a simple and commonly used tool used in epidemiological and demographical studies, but

| Age group | PALYs smokers status quo | PALYs non-smokers | PALYs lost to smoking | % PALYs lost | PALYs lost per smoker | PALYs gained with 50% reduction in smoking prevalence |
|-----------|-------------------------|-------------------|-----------------------|-------------|----------------------|-----------------------------------------------|
| Males (years) |                         |                   |                       |             |                      |                                               |
| 20–24 | 4 067 800 | 22 322 890 | 247 604 | 5.7 | 1.8 | 123 802 |
| 25–29 | 5 995 490 | 18 629 334 | 380 994 | 6.0 | 1.7 | 190 497 |
| 30–34 | 5 130 166 | 15 999 475 | 346 165 | 6.3 | 1.5 | 173 082 |
| 35–39 | 3 365 515 | 12 634 406 | 239 675 | 6.6 | 1.4 | 119 838 |
| 40–44 | 2 834 059 | 10 672 183 | 211 217 | 6.9 | 1.2 | 105 609 |
| 45–49 | 1 922 042 | 7 935 712 | 149 449 | 7.2 | 0.9 | 74 724 |
| 50–54 | 1 376 353 | 8 855 322 | 77 362 | 7.7 | 0.7 | 57 442 |
| 55–59 | 1 246 144 | 6 346 512 | 72 214 | 7.5 | 0.5 | 36 107 |
| 60–64 | 901 964 | 5 680 150 | 109 286 | 7.4 | 0.7 | 38 599 |
| 65–69 | 711 179 | 3 433 953 | 57 992 | 7.5 | 0.4 | 28 996 |
| All males | 25 780 437 | 99 354 362 | 1 772 214 | 6.4 | 1.1 | 886 107 |

Females | 20–24 | 3 040 226 | 15 211 816 | 144 023 | 4.5 | 1.0 | 72 012 |
| 25–29 | 2 401 996 | 15 231 600 | 118 851 | 4.7 | 1.0 | 59 426 |
| 30–34 | 2 076 982 | 13 205 345 | 108 518 | 5.0 | 0.9 | 54 259 |
| 35–39 | 1 579 019 | 10 145 572 | 86 319 | 5.2 | 0.8 | 43 160 |
| 40–44 | 1 376 353 | 8 855 322 | 77 198 | 5.3 | 0.7 | 38 599 |
| 45–49 | 1 246 144 | 6 346 512 | 72 214 | 5.5 | 0.5 | 36 107 |
| 50–54 | 901 028 | 4 601 493 | 54 838 | 5.7 | 0.4 | 27 419 |
| 55–59 | 404 381 | 2 905 416 | 25 928 | 6.0 | 0.3 | 12 964 |
| 60–64 | 199 767 | 1 619 124 | 13 065 | 6.1 | 0.2 | 6 533 |
| 65–69 | 36 453 | 518 505 | 197 5 | 5.1 | 0.0 | 988 |
| All females | 13 262 349 | 78 650 706 | 702 931 | 5.0 | 0.7 | 351 465 |

Total | 39 042 786 | 178 005 069 | 2 475 144 | 6.0 | 1.0 | 1 237 572 |

Data are n or % of PALYs of life lost at current smoking prevalence, or potential PALY gained (n) with a hypothetical 50% reduction in smoking prevalence across all ages and sex.

PALY, productivity-adjusted life years.

### Table 6

| Smoking prevalence reduction (%) | Deaths averted | QALYs gained | PALYs gained | Value of PALY gain ($A billion) |
|---------------------------------|---------------|--------------|--------------|--------------------------------|
| 10%                               | 40 644        | 602 877      | 247 514      | 38.8                           |
| 25%                               | 101 635       | 1 507 193    | 618 786      | 97.0                           |
| 50%                               | 203 269       | 3 014 386    | 1 237 572    | 193.9                          |
| 75%                               | 304 904       | 4 521 580    | 1 856 358    | 290.9                          |
| 90%                               | 365 884       | 5 425 896    | 2 227 630    | 349.0                          |

Data are n or value ($A of productivity gain) across a variety of hypothetical reductions in smoking prevalence (assumed to occur across all age groups and in both sexes).

PALY, productivity-adjusted life years; QALY, quality-adjusted life years.
has established limitations. It was assumed that age-specific mortality did not change over time (this is a well-known limitation called the ‘life table assumption’). However, as the relative impact of smoking is unlikely to change substantially, and the life table assumption was applied to both smokers and non-smokers, this would not have significantly impacted the conclusion that smoking imposes a significant burden on health and productivity. The third limitation stemmed from the assumption that there was no uptake or cessation of smoking over time within the modelled scenarios. Furthermore, the utility values and productivity indices used in this study were potentially imprecise, as they were not stratified for type of work. The impact of smoking on productivity is likely to differ across different types of jobs, and socioeconomic status. Similarly, assessment of the quality of life differences between smokers and non-smokers (from which QALYs are calculated) can vary by instrument, and is also potentially confounded by socioeconomic factors such as educational attainment, household income and occupation. We could not account for the duration of smoking among smokers, nor any socioeconomic differences between smokers and non-smokers, and other factors that may confound the association between smoking and utilities and productivity indices.

Fourth, like QALYs, PALYs are imprecise because they attempt to measure entities that are difficult to measure. Nevertheless, even with highly conservative assumptions regarding the effect of smoking on productivity among individuals, the collective impact is large. And perhaps the imperfections of PALYs will help stir debate, as QALYs initially did 40 years ago, which in turn will progress the science, economics, art and politics of health-related productivity.

Lastly, in terms of estimating impact on GDP, the present study assumed that all individuals and jobs contributed equally to GDP, which is not the case, and we assumed throughout the simulated follow-up, GDP would be stable, rather than increase. This last assumption would have led to an underestimation of the economic impact of smoking.

The findings of our study provide an important and novel assessment of the burden of smoking on the Australian population. They highlight the importance of preventing smoking, strategies for which, if effective, are very likely to be cost-effective, and possibly even cost-saving, in the long term. This issue is even more telling for populations within which the prevalence of smoking is very high, and those low-income and middle-income countries for whom the burden of productivity loss may be considerable, such as Indonesia, a close neighbour to Australia, for which smoking prevalence rates among men is as high as 65%. Future studies may also consider the type of jobs in the ‘working’ population when calculating productivity loss, as prevalence rates of smoking, and salaries/GDP per worker may differ, and smoking has been shown to be socioeconomically patterned.

CONCLUSION
Smoking imposes a very significant burden on the larger economy of Australia, despite that it is a country with a relatively low prevalence of smoking. Potential productivity gains for Australia with expansion of tobacco control measures are compelling. The likely economic benefits arising from productivity gains mean that greater investment in reducing the uptake of smoking is warranted.

What this paper adds

- Direct healthcare costs attributable to smoking are only a proportion of the economic burden imposed by tobacco.
- This study uses the novel concept of ‘productivity-adjusted life years’ (PALYs) to estimate the macroeconomic costs of smoking, and potential gains from smoking cessation.
- Following the current Australian smoking population to the age of 70 years, 2.4 million PALYs would be lost to smoking.
- Assuming that each PALY in Australia is equivalent to $A157 000 (gross domestic product per equivalent full-time worker in 2016), the economic impact of lost productivity over the working lifetime of current Australian smokers would amount to $A388 billion.

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