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

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► Additional material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/tobaccocontrol-2018-054263).

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Received 18 January 2018
Revised 4 June 2018
Accepted 6 June 2018
Published Online First 16 July 2018

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 $A157 000 (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.[1] In Australia, following adoption of a series of tobacco control measures,[2] age-standardised smoking prevalence decreased from 30.8% to 16.8% from 1980 to 2012.[3] 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.[4]

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.[5] 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.[6]

Price-based tobacco control measures (such as tobacco taxes) have been shown to be the most effective method for reducing tobacco consumption.[7] 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),[8] to examine the productivity burden of smoking in a contemporary Australian setting.

METHODS

We used life table modelling and decision analysis[9] 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.[8] 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 1). 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

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To cite: Owen AJ, Maulida SB, Zomer E, *et al*. *Tob Control* 2019;**28**:297–304.

Table 1 Modelled population

	Males			Females		
Age group (years)	**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.[13]
‡Percentage of total EFT workers from Australian workforce participation data.[15]
EFT, equivalent full time.

employment. Analyses were then repeated with the smoking cohort assumed to be non-smokers, and years of life, QALYs and PALYs lived 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[10] and productivity indices calculated from previously reported rates of absenteeism and presenteeism in smoking compared with non-smoking workers.[11]

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

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.[12] Smoking prevalence data were drawn from the Australian National Health Survey 2014–2015.[13] 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*,[14] 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.[10]

Productivity decrements due to smoking were estimated from a study by Bunn *et al* examining productivity loss due to smoking.[11] 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[15] (proportions in full-time and part-time work) 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*,[11] as above) to the age-specific workforce participation rates[15] (see online supplementary appendix 2). Assessment of upper and lower bound estimates for PALYs were drawn from 95% CIs for smoking-related work absences reported by Weng *et al*, which found that current smokers were absent from work for 1.54–3.95 more days per year than non-smokers.[16] For these upper and lower estimates, presenteeism data were not varied.

The cost of lost productivity due to smoking was estimated by assignment of a cost for each PALY, which was derived from total Australian gross domestic product (GDP) in 2016 ($A1 474 705 million)[17] divided by the estimated number of equivalent full-time (EFT) Australian workers in 2016 (n=9 411 998).[15] The figure for 2016 was $A157 000.

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).

Table 2 Deaths in Australian smokers and non-smokers over working life

	Deaths in total pop'n status quo	Remainder alive	Deaths in smokers status quo	Smoking-attributable deaths	Attributable risk %*	PAR%†
Males (years)						
20–24	136 451	715 367	44 411	26 618	59.9	19.5
25–29	156 353	729 037	72 258	43 473	60.2	27.8
30–34	152 816	724 059	70 932	42 905	60.5	28.1
35–39	129 128	656 542	54 463	33 158	60.9	25.7
40–44	130 441	689 502	55 381	33 962	61.3	26.0
45–49	115 149	659 230	46 869	29 045	62.0	25.2
50–54	1 05 325	663 982	43 557	27 433	63.0	26.0
55–59	82 686	631 898	31 991	20 636	64.5	25.0
60–64	56 286	576 576	22 826	15 331	67.2	27.2
65–69	21 981	548 601	6618	4700	71.0	21.4
Male total	1 086 616	6 594 794	449 304	277 261	61.7	25.5
Females (years)						
20–24	87 016	720 618	29 806	17 839	59.8	20.5
25–29	89 793	783 922	26 327	15 823	60.1	17.6
30–34	88 471	785 529	26 110	15 790	60.5	17.8
35–39	78 008	712 254	23 058	14 038	60.9	18.0
40–44	79 715	755 699	23 709	14 516	61.2	18.2
45–49	74 523	714 787	26 261	16 236	61.8	21.8
50–54	68 467	720 190	24 626	15 519	63.0	22.7
55–59	52 076	684 283	15 419	9990	64.8	19.2
60–64	38 471	615 075	11 088	7488	67.5	19.5
65–69	13 877	569 100	2855	2039	71.4	14.7
Female total	670 417	6 253 823	209 260	129 277	61.8	19.3
Total	**1 757 033**	**13 656 251**	658 564	406 538	**61.7**	**23.1**

Deaths are n.
*Attributable risk %=((deaths in smoker population−deaths in non-smoker population)/deaths in smoker population)×100%.
†PAR%=((deaths in smoker population−deaths in non- smoker population)/deaths in total population)×100%.
PAR, population attributable risk.

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), suggesting that interventions to reduce smoking prevalence specifically targeted to this group could be prioritised. Among males, the highest smoking prevalence was observed in the 25–34 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).

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

Age group	YOL lived by smoking cohort 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
2 5–29	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	3028	2.5	1.3
All females	29 677 206	202 701 034	914 602	3.0	1.5
Total	**70 879 647**	**401 892 998**	**3 141 928**	**4.2**	**2.2**

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

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 $A388 billion 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 an Australian cohort population by Banks *et al*, which estimated smoking increases mortality around twofold to fourfold in current smokers.[18] Our study estimated that current rates of smoking would cause >3 million years of life lost among 2.5 million Australian smokers aged 20–69 years when followed up until age 70 years. The 1997 Australian National Tobacco Campaign was estimated to have led to 190 000 people (of all ages) quitting smoking, and a gain of 323 000 years of life with follow-up until 85 years.[19] Hence, each quitter gained 1.7 years of life until age 85 years. This estimate is in accord with our estimate of 1.2 years of life lost per smoker followed up for an overall shorter period of time from 20 to 69 years to 70 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.

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.[20] A study in Chinese adults estimated smokers at age 35 years lost around 3 years of life when compared with people who never smoked,[21] 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.[22] 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.[23]

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.[8] 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

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	681 784	3 382 554	75 875	0.7	10.0	37 938
65–69	144 119	1 246 204	11 481	0.2	7.4	5741
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	16 852 454	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	6242	0.2	6.3	3121
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.

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.[6] 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.[24] 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.[25] 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.[26] 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.[27] 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.[28]

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

Table 5 The impact of smoking on PALYs in Australian adults over working life

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	1 373 426	5 680 150	109 286	7.4	0.7	54 643
55–59	711 179	3 433 953	57 992	7.5	0.4	28 996
60–64	324 373	1 564 574	26 076	7.4	0.2	13 038
65–69	56 387	481 685	3756	6.2	0.1	1878
All males	25 780 437	99 354 362	1 772 214	6.4	1.1	886 107
Females						
20–24	3 040 226	15 221 816	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	6533
65–69	36 453	518 505	1975	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.

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 programmes.

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 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

Table 6 Effect of proportional reductions in smoking prevalence on working lifetime national productive capacity among the Australian adult population of 2015

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 nor 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,[32] and is also potentially confounded by socioeconomic factors such as educational attainment, household income and occupation.[33] 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,[34] 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.[35] 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%.[36] 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.[37]

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.

Contributors AJO had the primary responsibility for writing this paper, in collaboration with SBM. All authors (AJO, SBM, EZ, DL) contributed to development and design of the model, interpretation of the results and review and comment on drafts of the paper. DL designed and supervised the study.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent Not required.

Ethics approval This study was approved by the Monash University Human Research Ethics Committee (ref# 8895) as a low-risk project.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement All data have been obtained from publicly available sources.

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