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Later school start times in the U.S.

An economic analysis

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Preface

This report presents the findings of a study on the economic implications of later school start times in the United States. The report follows a previous piece of research from RAND Europe on the economic costs of insufficient sleep (RR-1791-VH).

The report will be of interest to policy-makers, and the wider society and people interested in the field of sleep, health and wellbeing and economics in general.

RAND Europe is an independent not-for-profit policy research organisation that aims to improve policy and decision-making in the public interest through research and analysis. This report is joint work by researchers from RAND Europe and RAND Health and has been peer reviewed in accordance with RAND's quality assurance standards. For more information about RAND Europe or this document, please contact Marco Hafner (mhafner@rand.org):

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Abstract

Numerous studies have shown that later school start times (SST) are associated with positive student outcomes, including improvements in academic performance, mental and physical health, and public safety. While the benefits of later SST are very well documented in the literature, in practice there is opposition against delaying SST. A major argument against later SST is the claim that delaying SST will result in significant additional costs for schools due to changes in school bus transportation strategies. However, to date, there has only been one published study that has quantified some of the potential economic benefits of later SST in relation to potential costs. The present study investigates the economic implications of later SST by examining a policy experiment of a statewide shift in school start times to 8:30 a.m. and its subsequent economic effects. Using a novel macroeconomic modeling approach, the study estimates changes in the economic performance of 47 U.S. states following a delayed SST, which includes the economic benefits of higher academic performance of students and reduced car crash rates. The benefit–cost projections of this study suggest that delaying school start times is a cost-effective, population-level strategy that could have a significant impact on public health and the U.S. economy. From a policy perspective, these findings are crucial as they demonstrate that significant economic gains resulting from the delay in SST accrue over a relatively short period of time following the adoption of the policy shift.

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Background to the study

Up to 60 per cent of U.S. middle and high school students report weeknight sleep duration of less than the recommended (for this age group) 8 to 10 hours of sleep per night. While many factors have been found to be associated with adolescent sleep loss, including busy social lives, homework, participation in after school activities and use of technology in the bedroom, one other factor is a direct matter of public policy: school start times.

Known biological changes in adolescents contribute to delayed sleep–wake cycles. Sleep-wake cycles are in large part governed by the circadian rhythm, which controls the production of the sleep-inducing hormone melatonin. Adolescents experience major changes in their circadian rhythm, resulting in a roughly three-hour shift towards later bed and wake-up times compared to adults. At the same time of this well-documented biological shift in bedtimes and wake-up times however, school start times, particularly in the U.S., tend to shift earlier. Ideally, in order to accommodate early school start times, adolescents would go to bed early, but due to the biological change in sleep-wake cycles, they generally struggle to fall asleep early enough and do not get the adequate amount of sleep. As rise times for adolescents are primarily determined by school start times (SST), this results in an inherent conflict between adolescent biology and SST policy. Even though major medical and pediatric organizations recommend that middle and high schools should start no earlier than 8:30 a.m., data by the Centers for Disease Control and Prevention (CDC) suggests that about 80 per cent of U.S. middle and high schools start before 8:30 a.m., with a country-wide average of 8:03 a.m.

Indeed, empirical evidence suggests that later SST can improve adolescent sleep patterns, as it has been shown that following delayed SST, students get more sleep. With later starts, adolescent's bedtimes remain fairly constant but their wake-up times are extended, resulting in more weekday sleep. In addition, numerous studies have shown that later SST are associated with positive student outcomes, including improvements in academic performance, mental and physical health, and public safety. While the benefits of later SST are very well documented in the literature, in practice there is opposition against delaying SST. A major argument against later SST is the claim that delaying SST will result in significant additional costs for schools, for instance due to changes in school bus schedules. Given that many school districts are already facing significant shortages and economic challenges, concerns about added costs are understandably a significant deterrent to such a policy change.

However, despite the active public debate for and against the potential benefits of later SST, to date, there has been only one published study that has aimed to quantify some of the potential economic benefits of later SST in relation to potential costs. Specifically, a study by the Brookings Institution found that a one hour delay in SST would lead to a $17,500 lifetime earnings gain for students, compared to a cost of $1,950 over a student's school career.

This study provides a comprehensive economic analysis of later SST in the U.S.

The present study investigates in more detail the economic implications of later SST by examining a hypothetical policy experiment involving a universal state-wide shift in SST to at least 8:30 a.m. and its subsequent state-by-state economic effects. Using a novel macroeconomic modeling approach, the study compares changes in the economic performance of 47 U.S. states under a scenario with delayed SST, compared to the status quo of current SST.

As a first step, the model simulates the economic forecast of each of the states under consideration in the baseline scenario, using the current distribution of SST across middle and high schools data provided by the CDC. In a second step, under a different 'what if' scenario (compared to the current start times at baseline), the model predicts how the economic output (e.g. gross domestic product) of each state would change over time if the state implemented a universal shift to 8:30 am SST. The population directly affected by the policy change is students from grade 6 to grade 12.

The analysis presented in this report departs from the previous Brookings Institution benefit–cost analysis in several ways:

First, instead of assuming a one hour delay in school start time, the current distribution of school start times across different states provided by the CDC is taken into account and the impact of an 8:30 a.m. SST is modeled. Therefore, the model considers the impact of what could potentially be a relatively small change (approximately 30 minutes) for some states, given that the average start time is 8:03 a.m.

Second, instead of looking at the overall economic impact over the working life of an individual (i.e., up to 45 years), this analysis examines the year-by-year effects on the economy of delayed SST. From a policy and decision-maker's perspective it is important to understand when the effects of a policy shift occur, now, in 5 years, 10 years or in 50 years?

Third, when calculating the benefits of delayed SST, this study takes into account the effects on student lifetime earnings as well as the potential effects of reduced car crashes among adolescents, which can create a negative impact of the future labor supply of an economy if young adults die prematurely.

Fourth, the Brookings Institution analysis focused only on a general potential gain per student, partially based on data from a single school district in North Carolina, whereas this study takes a more national approach by predicting the economic implications for different regions, taking into account the variation of school start times and economic factors across different U.S. states.

Finally, this study also takes into account potential multiplier effects of increased lifetime earnings of individuals. For instance, at any given point in time, the additional income individuals save or consume will create further opportunities through further income for others agents in the economy.

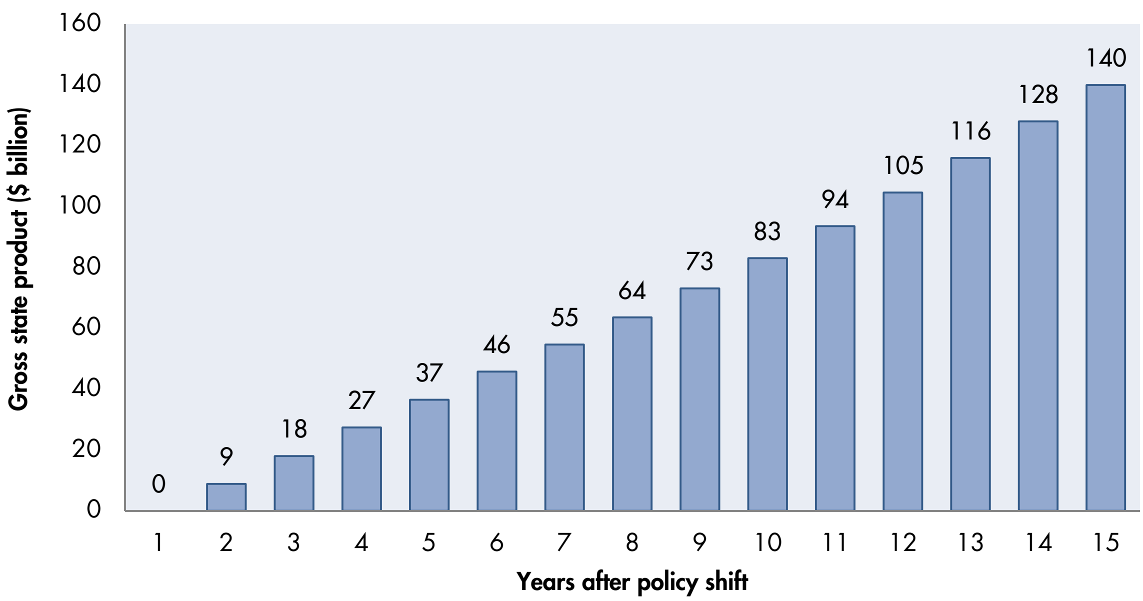
Overall, this study takes a conservative approach and the reported benefits in this study are likely an underestimation of the full benefits related to delaying SST to at least 8:30 a.m. That is, in the modelling process only parameters in the calibration process of the model have been applied for which robust empirical evidence is available in the literature concerning the impact of sleep loss on adolescents' health and academic performance. Specifically, only the effects of car crash mortality and impaired academic performance are modeled and other potential impacts of insufficient sleep, such as the effects on mental health, including depression and suicide, or other potential negative effects related to obesity or other morbidities that are also associated with insufficient sleep have not been taken into account.

In the calculation of the benefit-cost ratios associated with a delay in SST two types of potential cost are taken into account. First, it is documented that the largest cost of delaying SST in the U.S. would incur from changes in school bus schedules, which have been estimated to be around $150 per student per year. Second, some argue that a delay in SST may impose a need for rescheduling after-school activities such as sports team practices, due to later school dismissals and diminishing outdoor light for evening practices or games. The costs of making additions to school infrastructure (e.g. additional lighting equipment) to accommodate delayed SST have been estimated to be $110,000 per school. In order to test the robustness of the benefit-cost ratios against higher cost assumptions and to take into account additional cost that potentially could arise from delaying SST (e.g. additional childcare expenses), further cost scenarios have been applied in the analysis.

Study predicts economic gains from a delay in school start times across the U.S.

This study illuminates the link between a delay in SST and profound economic gains across 47 U.S. states, showing that a state-wide universal move to at least 8:30 a.m. could contribute $83 billion to the U.S. economy within a decade (see Figure ES 1).

Figure ES1: Predicted cumulative economic gains from delayed SST to 8:30 a.m.



Source: Authors' calculations.
Notes: The figure plots the predicted discounted cumulative gains (2016 $) of delayed SST to 8:30 a.m. in gross state product (GSP) terms, aggregated across 47 U.S. states. GSP is a measurement of a state's economic output and is the state counterpart to gross domestic product (GDP) at country level.

As it would take at least a year until the first student cohort that benefited from the policy shift enters the labor market, the gains are zero in the first year. However, already after just two years, the study projects a cumulative economic gain of about $9 billion, which gradually increases over time as more student cohorts will benefit from the policy shift in terms of higher academic performance (e.g. higher likelihood to graduate from high school or college) and reduced car crash mortality. After 15 years, the cumulative economic gain is predicted to be around $140 billion. On average, this corresponds to an annual gain of about $9.3 billion each year, which is roughly the annual revenue of Major League Baseball (MLB).

Delaying school start times is cost-effective population-level strategy that benefits public health and the economy

In line with previous studies, the economic analysis presented in this report suggests that later SST could be a cost-effective population strategy with a substantial impact on public health and the U.S. economy. The predicted benefit cost-ratios per student suggest that under reasonable cost assumptions, even after a relative short period of time, the benefits will outweigh the costs (see Table ES1).

For instance, after 5 years of the shift to at least 8:30 a.m. SST, the average predicted benefit-cost ratio is between 1.7 and 2.1, meaning that for every $1 spent, the return is between $1.7 and $2.1. Even after only 2 years following the adoption of later SST, it is predicted that some states (e.g. Connecticut, Massachusetts, Rhode Island) would break even and achieve a benefit-cost ratio of at least 1 (meaning that $1 spent is at least paid back). The benefit-cost ratios increase over time and range between 3.46 and 3.73 after 20 years.

Table ES1: Predicted benefit–cost ratios by state over time

	Years after policy shift									
	2 years		*5 years*		*10 years*		*15 years*		*20 years*	
State	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Alabama	0.11	0.07	0.35	0.29	0.75	0.67	1.28	1.17	1.75	1.62
Arizona	1.27	0.81	2.16	1.74	2.63	2.32	3.14	2.86	3.59	3.33
Arkansas	0.65	0.41	1.30	1.05	1.51	1.33	1.93	1.76	2.30	2.13
California	1.14	0.73	1.95	1.58	2.45	2.16	3.01	2.74	3.55	3.29
Colorado	1.00	0.64	1.73	1.39	2.27	2.01	2.97	2.71	3.54	3.29
Connecticut	1.76	1.12	3.18	2.57	4.10	3.63	5.11	4.66	5.96	5.53
Delaware	2.49	1.59	4.41	3.56	5.72	5.06	7.08	6.46	8.15	7.56
Florida	1.55	0.99	2.57	2.07	3.12	2.75	3.76	3.43	4.31	4.00
Georgia	0.91	0.58	1.58	1.28	1.96	1.74	2.37	2.16	2.75	2.55
Hawaii	1.62	1.03	3.30	2.67	3.71	3.28	4.35	3.97	5.02	4.66
Idaho	0.61	0.39	1.06	0.85	1.32	1.17	1.62	1.47	1.91	1.77
Illinois	0.88	0.56	1.56	1.26	2.01	1.77	2.59	2.37	3.16	2.93
Indiana	0.93	0.59	1.83	1.48	2.23	1.97	2.94	2.68	3.52	3.26
Iowa	1.34	0.86	2.34	1.89	2.91	2.57	3.32	3.03	3.77	3.49
Kansas	0.98	0.63	2.13	1.72	2.46	2.18	3.01	2.74	3.54	3.28
Kentucky	0.89	0.57	2.08	1.68	2.40	2.13	2.83	2.59	3.23	3.00
Louisiana	1.29	0.83	2.29	1.84	2.94	2.60	3.70	3.38	4.35	4.04
Maine	0.93	0.60	1.65	1.33	2.17	1.92	2.71	2.47	3.18	2.95
Massachusetts	2.39	1.53	3.88	3.13	4.48	3.96	5.22	4.76	5.91	5.48

State	2 years (1)	2 years (2)	5 years (1)	5 years (2)	10 years (1)	10 years (2)	15 years (1)	15 years (2)	20 years (1)	20 years (2)
	Years after policy shift									
Michigan	1.12	0.72	1.97	1.59	2.57	2.27	3.10	2.83	3.56	3.30
Minnesota	1.22	0.78	2.08	1.68	2.68	2.37	3.27	2.98	3.80	3.52
Mississippi	0.60	0.38	1.23	1.00	1.46	1.29	1.79	1.64	2.10	1.95
Missouri	1.16	0.74	2.01	1.62	2.61	2.31	3.39	3.09	3.99	3.70
Montana	1.15	0.73	1.97	1.59	2.33	2.06	2.68	2.45	3.05	2.83
Nebraska	0.88	0.56	1.58	1.27	2.00	1.77	2.51	2.29	3.03	2.81
Nevada	0.65	0.41	1.14	0.92	1.50	1.33	1.92	1.75	2.31	2.14
New Hampshire	0.97	0.62	1.93	1.56	2.46	2.18	3.12	2.85	3.68	3.41
New Jersey	1.87	1.20	3.18	2.56	4.04	3.57	4.89	4.46	5.61	5.20
New Mexico	1.27	0.81	2.12	1.71	2.58	2.28	3.00	2.74	3.41	3.16
New York	1.00	0.64	1.79	1.45	2.35	2.07	3.05	2.79	3.71	3.44
North Carolina	1.16	0.74	2.03	1.64	2.54	2.25	3.12	2.85	3.64	3.38
Ohio	1.39	0.89	2.37	1.91	2.77	2.45	3.27	2.98	3.72	3.45
Oklahoma	0.99	0.63	1.66	1.34	2.03	1.79	2.44	2.22	2.82	2.62
Oregon	1.00	0.64	1.73	1.39	2.18	1.93	2.77	2.53	3.34	3.10
Pennsylvania	0.94	0.60	1.75	1.41	2.36	2.09	3.10	2.83	3.73	3.46
Rhode Island	1.83	1.17	3.46	2.80	4.23	3.74	5.02	4.58	5.70	5.28
South Carolina	1.08	0.69	1.99	1.60	2.41	2.13	2.74	2.50	3.07	2.85
South Dakota	1.01	0.64	1.87	1.51	2.17	1.92	2.56	2.34	2.97	2.75
Tennessee	0.76	0.49	1.39	1.12	1.81	1.60	2.31	2.10	2.76	2.56
Texas	1.13	0.72	1.92	1.55	2.38	2.10	2.90	2.64	3.38	3.13
Utah	0.77	0.50	1.34	1.08	1.84	1.63	2.28	2.08	2.67	2.47
Vermont	1.24	0.79	2.19	1.77	2.74	2.42	3.39	3.09	3.95	3.66
Virginia	2.02	1.29	3.07	2.47	3.77	3.34	4.44	4.05	5.08	4.71
Washington	1.71	1.09	3.32	2.68	3.78	3.34	4.42	4.03	5.03	4.66
West Virginia	0.80	0.51	1.40	1.13	1.79	1.58	2.20	2.01	2.57	2.38
Wisconsin	1.22	0.78	2.16	1.74	2.82	2.50	3.48	3.17	4.06	3.77
Wyoming	1.57	1.00	2.85	2.30	3.55	3.14	4.35	3.97	5.05	4.68
Average	**1.18**	**0.75**	**2.10**	**1.70**	**2.62**	**2.31**	**3.20**	**2.92**	**3.73**	**3.46**

Source: Authors' calculations.
Notes: Column (1) assumes cost of $150 per student per year and column (2) assumes that in addition to the $150 per student per year, each school has to invest $110,000 upfront for updates in school infrastructure related to after-school activities (e.g. update of lighting equipment).

Discussion

The findings of this study are based on a simulated or hypothetical "natural experiment" which presupposes a statewide universal shift in school start times to 8:30 a.m. or later. This presupposition may seem unjustified given that start times are generally determined at the local district level. However, there are several examples of proposed policy initiatives in states across the country, including a bill that is under consideration in the California state legislature, which mandates that California middle and high schools start no earlier than 8:30 a.m. Thus, the hypothetical policy shift modeled in the current analysis is potentially a conceivable strategy. In the economic analysis, only the benefits of better academic performance and lower mortality from car crashes are modeled; however, as mentioned, there are numerous other potential costs associated with mental and physical morbidity that were not included in the model predictions, and yet are known to be associated with insufficient sleep among adolescents. For instance, it has been documented that the combined public health costs of the obesity epidemic in children and adolescents and its associated cardiovascular morbidities are significant, and sleep loss is longitudinally associated with increased risk of obesity in children and adolescents. Further, insufficient sleep among adolescents is associated with an increased risk of engaging in property and violent crime. The direct and indirect costs of crime, including direct economic losses, increased insurance rates, loss of productivity, and various aspects of the criminal justice system, from police, to courts, to juvenile facilities and prisons, are potentially substantial. In addition, the robust association between insufficient sleep and poor sleep quality and adolescent risk for mental health problems and other risk-taking behaviors, including substance use, could also contribute to substantial societal costs.

In summary, it is important to put these economic findings in context. The predictions of this study, as well as the Brookings Institution findings, suggest that the benefits of later start times likely outweigh the immediate costs. Moreover, when paired with the substantial literature demonstrating the dire public health consequences of insufficient sleep among adolescents, the multitude of health and academic benefits associated with later start times, and the lack of any scientific evidence to suggest that there are benefits to having adolescents start school earlier, these findings are relevant to policymakers, educators, and community members and suggest that in addition to the well-documented public health benefits, later start times may also yield significant economic benefits.

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Abbreviations

CDC	Centers for Disease Control and Prevention
CGE	Computable General Equilibrium model
GDP	Gross Domestic Product
GSP	Gross State Product
OLG	Overlapping generations model
SST	School Start Time

1. Introduction

1.1. Inadequate sleep among adolescents: a public health problem

Even though it is recommended that adolescents should get an average of 8 to 10 hours of sleep each night (NHLBI, 2012), up to 60 per cent of U.S. middle and high school students report weeknight sleep duration of less than 8 hours per night (Basch et al., 2014). The existing literature has shown that a lack of sleep among adolescents is associated with a diverse set of adverse outcomes, including poor physical and mental health, behavioral problems, suicidal ideation and attempts, attention and concentration problems, and suboptimal academic performance (Short et al. 2013; Pallesen et al. 2011; Pasch et al. 2010). Insufficient sleep in adolescents has further been linked with lower levels of physical activity, increased food intake and obesity, as well as unhealthy risk behaviors such as alcohol use, smoking, and marijuana and other illicit drug use, all of which can set the stage for chronic health conditions in adulthood (Lowry et al. 2012; Lytle et al. 2011; Hart et al. 2013; McKnight-Eily et al. 2011; Winsler et al. 2015; O'Brien and Mindell 2005; Kubiszewski et al. 2014). Furthermore, inadequate sleep among adolescents has been associated with motor vehicle crashes, the leading cause of death of adolescents in the United States (GHSA, 2015).

Many factors have been found to be associated with adolescent sleep loss, including busy social lives, homework, participation in after school activities and use of technology in the bedroom (Carskadon, 2002). Furthermore, known biological changes in adolescents contribute to delayed sleep–wake cycles. Sleep-wake cycles are, in large part, governed by the circadian rhythm, which controls the production of the sleep-inducing hormone melatonin. Adolescents experience major changes in their circadian rhythm, resulting in a roughly three-hour shift towards later bed and wake-up times compared to adults or younger children (Crowley et al., 2007).[1] Concurrent with the adolescent shift in sleep-wake schedules, towards later bedtimes and later rise times, most middle and high schools, particularly in the U.S. shift towards earlier school start times. Ideally, in order to accommodate early school start times, adolescents would go to bed early, but due to the biological change in sleep-wake cycles, it has been documented that they generally struggle to fall asleep early enough and to get the adequate amount of sleep. Rise times for adolescents, during the weekdays, are primarily determined by school start times (SST), which is a factor of public policy, resulting in an inherent conflict between adolescent biology and SST policy (Shapiro, 2015).

[1] For instance, due to the delayed sleep-wake cycles, a 7:30 a.m. start for an adolescent is the equivalent to 4:30 a.m. for an adult.

In order to accommodate the known biological shift in adolescent sleep–wake cycles, major medical and pediatric organizations, including the American Medical Association, the American Academy of Pediatrics, the American Academy of Sleep Medicine, and others, recommend that middle and high schools should start no earlier than 8:30 a.m. (Owens et al. 2010). Despite these recommendations, a Centers for Disease Control and Prevention (CDC) study estimated that 82 per cent of middle and high schools start before 8:30 a.m., with an average start time across the United States of 8:03 a.m., highlighting significant variation in SST across different U.S. states (Wheaton et al, 2015).

1.1.1. Empirical evidence on the benefits of later school start times

The empirical evidence suggests that later SST generally represent a measure to improve adolescent sleep patterns. For instance, the existing literature suggests that following delayed SST adolescents' bedtimes remain fairly constant (i.e., bedtimes are not delayed), but rise times are extended, leading to longer weekday sleep duration among U.S. adolescents (Minges and Redeker 2016; Paksarian et al. 2015; Boergers et al. 2014). Furthermore, several studies have highlighted that early SST are indeed associated with physical and mental health risks for adolescents, with earlier start times associated with increased tardiness and poorer attendance, and higher rates of motor vehicle accidents, suicidal ideation and depression (Adam et al. 2007; Vorona et al. 2014; Danner and Phillips 2008). Conversely, literature has shown that delaying SST can be linked to an improvement of attention and better academic performance (Lufi et al. 2011; Wahlstrom et al. 2014), as well as improvements in measures of health, well-being, and safety.

With regard to the academic effects of SST, the empirical literature using natural experiments and exogenous variation in start times finds relatively large benefits for students, especially compared to other educational measures such as improving teacher quality or reducing class sizes (Shapiro, 2015). For instance, investigating variation in SST between and within middle schools in Wake County (North Carolina) a study found that an increase in SST by one hour would lead to a three percentile point increase in standardized math and reading test scores for the average student (Edwards, 2012). To put into context, these effects on standardized test scores following a delay in SST are of similar magnitude as compared to reducing class sizes by one-third fewer students. Similar results have been found for standardized test scores among first-year U.S. Air Force Academy students, where a 50-minute delay in start times led to a 0.15 standard deviation increase in standardized course grades from improved performance in earlier classes but also classes during the day (Carrell et al., 2011). Putting the improvements in test scores into economic perspective, the existing literature suggests that a one standard deviation increase in test scores is associated with an increase in a student's future earnings by about 8 per cent (Shapiro, 2015).

1.1.2. The potential cost of delaying school start times

While the health and educational benefits of later SST are very well documented in the literature, in practice, there is often opposition against delaying SST. A major argument against later SST is the concern that delaying SST will result in significant additional costs to school districts and communities endeavoring to make a change in SST. Specifically, altering current school bus schedules and moving after-school activities to later in the day are often highlighted as major cost factors related to delaying SST (Owens et al., 2010).

It is estimated that the largest cost of later SST in the U.S. would incur from changes in school bus schedules from the current three-tier to a one-or two-tier school bus systems. Specifically, in order to reduce the total number of school buses, many school districts stack start times according to the three school levels, elementary, middle and high school, generally with middle and high schools starting first. Often high-school starts first because of safety concerns arising from having younger children walking to school or waiting for buses early in the morning when it is potentially still dark outside. That is, schools that currently provide transportation for students would likely have to reduce the bus tiers and invest and operate more buses amid a delay in SST. Previously, these costs have been estimated to be approximately $150 per student per year, or about $1.950 over a student's school career (Edwards, 2012).

Furthermore, a delay in SST may impose a need for rescheduling of after-school activities such as sports team practices, due to later school dismissals, and diminishing outdoor light for evening practices or games. In order to offset this, some schools may opt for installing new lighting systems on sport fields which would allow for outdoor practice and games later in the day. The costs of adding light equipment have previously been estimated to a total one-time expense of around $110,000 and yearly operating costs of around $2,500 (Jacob and Rockoff, 2011). However, other approaches to offset the negative impact on sports and outdoor field time have been offered, such as altering student class schedules in order to make the last hours of the schedule available for sports activities, or to move activities indoors, which would mitigate the issue and hence reduce cost (Jacob and Rockoff, 2011).

1.2. Objectives of the study

Despite the public debate on the implementation challenges of later SST, including concerns about potential increased costs, so far only one study has aimed to quantify some of the potential economic benefits of later SST and compared them against the potential costs. Specifically, the analysis by the Brookings Institution (Jacob and Rockoff, 2011) examined the cost and benefits of delaying SST and found a benefit–cost ratio of 9:1 for a one hour later start time among middle and upper grades. In other words, for every $1 spent, the return is $9. Cumulatively, the study estimated an average $17,500 gain per student in terms of lifetime earnings compared to $1,950 cost per student over the school career. While the Brookings analysis shows a high benefit-to-cost ratio, it is important to highlight that the total time horizon of the potential benefits to occur is around 45 years, the average working life of an individual. However, from a political decision-makers' perspective, it is important to have a more granular understanding of the timeframe when these benefits are likely to accrue.

Against this background and to facilitate decision-making among policy makers, the present study examines the potential economic consequences from delaying SST to at least 8:30 a.m. across the United States and predicts future potential benefits on an annual basis. This directly follows the recommendation by major medical organizations, like the American Academy of Pediatrics (AAP), which recommends that middle and high schools start at 8:30 a.m. or later, to give students the opportunity to get the amount of sleep they require.[2] Specifically, the main research questions addressed in this study are:

1) What are the economic implications of a state-wide universal shift in start times for middle and high schools to at least 8:30 a.m.?
2) What is the expected time horizon for potential benefits to occur?
3) How are the economic effects distributed across different states?

In order to answer these research questions, this study runs a hypothetical policy experiment which presupposes a statewide universal shift of SST to at least 8:30 a.m. Although the presupposition for this policy experiment may seem unjustified given that start times are generally determined at the local district level, there are, in fact, recent examples of proposed policy initiatives across the United States, including a bill that is currently under consideration in the California State Senate, which mandates that California middle and high schools start no earlier than 8:30 a.m.[3] Hence, the hypothetical policy shift examined in this analysis represents a generally conceivable strategy.

The analysis presented in this report departs from the Brookings Institution benefit–cost analysis in several ways. First, instead of assuming a one hour delay in school start times, the current distribution of start times across different states is taken into account and the impact of an 8:30 a.m. SST is modeled. Second, this analysis examines the year-by-year effects on the economy of delayed SST, as opposed to examining the overall impact over the whole working life of an individual, which is about 45 years. From a policy and decision-maker's perspective it is important to understand when the effects of a policy shift occur; now, in 5 years, 10 years or in 50 years? From a policy-maker's perspective, that time horizon may have significant implications for garnering public support and decision-making. Third, when calculating the benefits of delayed SST, this study takes into account the effects on student lifetime earnings as well as the potential effects of reduced car crashes among adolescents, which can create a negative impact of the future labor supply of an economy if young adults die prematurely. Fourth, the Brookings Institution analysis focused only on a general potential gain per student, whereas this study looks at potential economic implications for different regions, taking into account the variation of start times and economic factors across different U.S. states. Finally, this study also takes into potential multiplier effects of increased lifetime earnings of individuals. For instance, at any given point in time the additional money these individuals save or consume will create further opportunities through further income for others agents (e.g. firms) in the economy.

1.3. Research approach

In order to address the research objectives and questions formulated above, the research incorporates two main methodological strands:

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[2] Note that no study has yet established the optimal school start time. However, among existing studies it has been shown that even relative small delays in the hours between 7:00 a.m. and 8:00 a.m. are associated with better student performance.

[3] Senate Bill No. 328, California Legislature – 2017-2018 regular season. "An act to add Section 46148 to the Education Code, relating to pupil attendance." Published 26/04/2017.

1) **Literature review**: we review the available literature in order to collect available evidence about the relation between sleep and wider health outcomes, mortality, and academic performance of adolescents. The literature review also serves to identify and extract parameters relevant for the economic model developed in the analysis.
2) **Macroeconomic model development and calibration:** we apply a macroeconomic model that enables the assessment of the economic implications of later SST across different U.S. states. In essence, the economic model used in this analysis is an overlapping generations (OLG) model, which by definition assumes that the modelled economy is represented by people of different age cohorts. In a nutshell, the economy in our model has three main actors – households, firms, and government – which continuously interact with the markets, just as in reality. Specifically, firms, representing the production sector, hire labor supplied by households to create output, paying wages in exchange for labor and interest rate as a cost of capital. In addition, the government collects income taxes from individuals and subsequently provides them with retirement and other social benefits. The strength of the model is that it enables the modelling of factors that affect different economic agents at different stages of their lifetime. For instance, for the purpose of this analysis, the policy change modelled affects individuals while they are in the education system and hence, before they enter the labor market. Subsequently, the modelling framework enables the quantification of a policy impact through comparison of the current status quo (no policy change) to a 'what if' scenario in which a change of policy affects agents in the economy in different ways. We outline the specifics of the model in more detail in Chapter 2 and Appendix A.

Note that in predicting the economic impacts of delaying SST, the study follows a generally conservative modelling approach. For instance, only those effects for which robust evidence is available in the relevant adolescent sleep literature (i.e. academic performance, car crashes) are modelled and whenever possible only parameter values are applied that lead to a potential underestimation of the benefits. Furthermore, it is important to highlight that the model applied in this analysis depends on parameters for calibration that stem from external sources and in the data collection process assumptions had to be made to make them tractable as modelling inputs. At every stage of the modelling description the assumptions and their implications are highlighted.

1.4. Structure of this report

This report is organized as follows: Chapter 2 outlines the methodological approach taken and describes in more detail the data used in the analysis. Chapter 3 reports the findings from the economic analysis of delayed SST for the whole United States and separately by each state. Chapter 4 summarizes the findings of the study and concludes.

2. Methodological approach

This chapter outlines the research approach taken for this study. Specifically, the model to analyze the economic implications of delayed SST is described in more detail, together with a description of the data used in the analysis.

2.1. General modeling approach

The economic analysis is based on a theoretical dynamic general equilibrium model related to a system of mathematical equations to characterize the different economic interaction of different agents in an economy such households, firms, or the government. The economic model builds on the long tradition of computable general equilibrium (CGE) models, which have been extensively applied for economic policy analysis (see for example Allan et al., 2014; Lofgren et al., 2013; Zodrow & Diamond, 2013). CGE models are based on a detailed theoretical framework simulating the behavior of various agents and depicting relationships between subjects in an economy described by a set of parameters, equations and conditions that are to be satisfied simultaneously. The equations are then evaluated using mathematical software,[4] giving a set of numerical results representing, for example, the labor or capital stock in a simulated economy. CGE models explicitly allow for the analysis of multiple comparable scenarios which differ only in the selected set of parameters, for example, by creating either a baseline (or status quo) and a 'what if' situation showing how the economy would evolve under alternative policy scenarios.

The specific model applied in this study is based on a family of general equilibrium models, a so-called overlapping generations (OLG) model. OLG models have been developed to account for complex economic interactions involving more than one generation of people. The basic mechanism behind the OLG modeling approach is driven by the life choices of representative economic agents (e.g. individuals in households) regarding education, labor supply, savings, investments and retirement based on a utility function that determines their preferences at any given point in time throughout their lifetimes. Specifically, the simplified model economy in each state of the analysis consists of three agents – individuals/households, firms, and government – which continuously interact on different markets, just as in reality. For instance, firms, representing the production sector, hire labor supplied by households to create output, paying wages in exchange for labor and interest as a cost of capital. Households buy goods and services with the income they receive from their labor supply. Within the model economy all assets are ultimately in possession of people, who also constitute the final consumer of all produced goods in the

[4] For the purpose of this analysis we use MatLab. See https://uk.mathworks.com/products/matlab

economy. In addition, the government collects taxes from individuals and subsequently produces a public good and provides households with retirement and other transfers. In other words, in each state, profit-maximizing firms demand inputs from the factor markets (e.g. labor and capital) and compare these costs with the revenue they expect from selling the final goods in the product market. This forms the production side of the economy. Simultaneously, consumers/households are endowed with capital and labor, which they offer on the factor markets. Consumers then demand a bundle of goods produced by firms to maximize their utility, subject to their budget constraints, which forms the demand side of the model. In equilibrium, prices adjust so that demand and supply is equal. In principle, the model assumes the economy to be populated by individuals of different age cohorts who make decisions about schooling in earlier years, then enter the labor market and produce goods, receive wages for their labor, pay taxes and receive unconditional pensions from the government in retirement. Appendix A provides a more detailed model description, together with a table that describes the relevant model calibration parameters.

2.2. How a delay in SST is captured in the economic model

As a first step, the model simulates the economic forecast of each state in the baseline scenario, using the current distribution of SST across middle and high schools in different U.S. states provided by the CDC (Wheaton et al., 2015). Note that the CDC data does not provide average school start time for the District of Columbia and Maryland and the average start times in Alaska and North Dakota are later than 8:30 a.m. Hence, included in the analysis are the 47 U.S. states for which the SST distribution is available and is currently earlier than 8:30 a.m. In a second step, under a different 'what if' scenario (compared to current start times at baseline), the model predicts how the economic output of each state would be affected if the state would implement a universal shift to at least 8:30 a.m. SST. Or, in other words, how much would the economic welfare change in each state year-by-year after introducing the policy of delaying SST?

In the applied economic model, the population directly affected by the policy change is adolescents from school grade 6 to grade 12 and it is assumed that delaying SST leads to extended sleep duration for adolescents, which subsequently affects the economy in a given state through different channels.[5] Specifically, only effects are included for which there were sufficiently robust and suitable parameters from the existing literature available. In particular, this study focuses on two specific beneficial channels that could be derived from later SST: [6]

The first channel is mortality from motor vehicle crashes. The data for car crash mortality includes the underlying cause of death data provided by the CDC on weekday motor vehicle fatalities among teenagers

[5] Note that the empirical literature suggests that delaying SST is not associated with later bed time, but is associated with later rise times, which results in a net increase in sleep duration among students (see for example the systematic review by Minges & Redeker, 2016).

[6] For instance, while it has been documented that longer sleep duration can be associated with improvements in mental and physical health outcomes for students, including lower levels of depression, suicide ideation or calorie intake, it has been proven difficult to translate the existing empirical estimates on these effects into suitable model parameters. Similar applies to the potential morbidity and disability implications of car crashes involving adolescents, which could lead to large medical expenses, disability payments and a potential loss of future earnings. As this study does not take these effects into account, the predicted economic effects serve as a lower bound estimate.

age 16 to 18,[7] combined with parameters from a study by the AAA Foundation for Traffic Safety, which revealed that about one fifth of fatal motor vehicle crashes involved a driver impaired by sleepiness, drowsiness or fatigue (Tefft, 2014). Together with the estimate by Danner & Phillips (2008), which suggests that the car crash rate decreases by 16.5 per cent due to an hour delay in SST, the potential reduction of car crash mortality rates for each state is calculated.[8] Note that in the applied economic model, reduced mortality levels among adolescents increase the potential future labor population and therefore has a positive effect on the economy. Thus, the labor supply effect on the economy derived from motor vehicle mortality data consists of two factors: 1) the direct impact of the individual being alive and productive; and 2) the impact on the individual's potential future offspring, which will subsequently be missing and hence will not contribute to the economy in the future.

The second channel potentially contributing to the benefits of later SST is the impact on academic performance. Using parameters on the effect of adolescent sleep on academic performance and graduation rates from Wang et al. (2016), the model takes into account that longer sleep can lead to increased high school and college graduation rates. Specifically, Wang et al. (2016) estimate that one additional hour of sleep is estimated to increase the probability of high school graduation on an average by up to 8.6 per cent (with decreasing marginal returns as the second-order effect is estimated at -0.5 per cent) and the college attendance rate by 13.4 per cent (with second-order effect of -0.9 per cent). Due to the non-linear effect of sleep duration, Wang et al.'s findings suggest that later start times may create long-run human capital benefits especially for those adolescents that sleep on average less than 7 hours a night, which applies roughly to between 40 per cent and 60 per cent of the adolescent population between ages 12 to 19 (e.g. Keyes et al., 2015).[9] The positive effect on adolescents' academic performance and likelihood of high school and college graduation, in turn, impacts the jobs they are able to obtain in the future. This has a direct effect on how much a particular person contributes towards the economy in future financial earnings. Due to the dynamic nature of the model, at any given point in time, the increased income these individuals save or consume will create further opportunities through additional income for other agents in the economy.[10]

Note that a shift to 8:30 a.m. SST is likely associated with some costs, and hence it is relevant to compare the economic benefits of the delayed SST to its potential costs. As mentioned, one of the most important factors driving costs is a change in the bussing system from a three-tier to a one- or two-tier system. The Brookings Institution analysis (Jacob and Rockoff, 2011) uses a cost estimate of $150 per student per year for the benefit–cost analysis, based on estimates from a school district in Wake County, North Carolina. Importantly, the cost will depend on the local circumstances of each state, and even at the more granular school district level it is impossible to representatively estimate them across the USA. Hence, for the

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[7] WONDER online database, available at https://wonder.cdc.gov/

[8] Note that some studies found up to 70 per cent decreases in car crashes in some districts following a delay in SST by one hour (Wahlstrom et al., 2014).

[9] The study by Keyes et al. (2015) suggests that less than 60 per cent of students aged 12 to 19 get 7 or more hours of sleep per night. Hence, in order to be conservative in the predictions of economic benefits of delayed SST, in the analysis only students that sleep on average less than 7 hours will profit from the policy shift of later SST to 8:30 a.m. or later.

[10] In economics this is referred to as the well-known "multiplier effect", which is when extra income leads to more spending in the economy which subsequently can create more income.

purpose of illustration of the potential benefit–cost ratios, different cost scenarios are applied in the present analyses to provide a more comprehensive range of potential costs. The scenarios include different values of annual costs per student, including \$150, \$350, and \$500.[11] It is assumed that these cost per student will occur in perpetuity after the policy shift to 8:30 a.m. SST, which is likely overestimating the actual costs as the majority of the costs in relation to make changes to bussing systems would probably accrue at the beginning of the policy shift in the form of upfront investments for new buses. In addition, the cost scenarios also include some cost factors that may occur as upfront investment which are assumed to be related to updates of school infrastructure (e.g., athletic field lighting) in order to accommodate after school-activities.

2.2.1. Model dynamics

In the model, the economic output of state s consists of goods and services Y_s that are produced using input factors capital K_s and effective labor L_s (e.g. labor input adjusted for efficiency units), and hence production is modeled as a function of $Y_s = F(K_s, L_s)$. In each time period t, the model assumes that physical labor is adjusted for efficiency units by $L_s = \bar{L} * \theta$ with the physical supply of labor input $\bar{L}$ and efficiency labor θ, which represents population levels in productivity.[12] As the delay in SST directly impacts the labor component of the model, the law of motion of the components of L_s, in both the baseline and the "what if" policy scenario, needs to be derived.

Physical labor

To address the first component, physical labor $\bar{L}$, a cohort-component model is applied to predict the size of the future populations in each state using current base population estimates from the United States Census Bureau,[13] as well as mortality and fertility rates data provided by the CDC.[14]

Specifically, the cohort-component model starts with the base population in each state and is categorised by age and gender. The base population subsequently evolves by applying assumptions on mortality and fertility so that the population changes according to a 'natural' increase (births minus deaths), which depends on the particular scenario.[15] The outcome of the model is a projection of the population by 1-year age and gender groups into the future, applied to each of the states.

[11] While it is difficult to precisely model the cost implications of other factors such as increased stress on family and home life, we assume that the additional higher cost estimates applied in the model would cover some of these potential costs. In addition, it is assumed in the model that a delay in SST would not affect parent's labor supply, meaning that there is no strong evidence in the literature suggesting that a delay of roughly 30 mins to 60 mins would induce parents of 6 to 12 grades to alter their hours of work or stop working altogether.

[12] Note that we refer to the labour efficiency effect as "productivity". However, alternatively one could also use the term "human capital" as the underlying assumption is that higher levels of human capital lead to higher levels of productivity.

[13] Available at https://www2.census.gov/programs-surveys/popest/datasets/2010-2015/state/asrh/

[14] Centers for Disease Control and Prevention, National Center for Health Statistics. Compressed Mortality File 1999–2015 on CDC WONDER Online Database, released December 2016. Data are from the Compressed Mortality File 1999–2015 Series 20 No. 2U, 2016, as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program. Accessed at http://wonder.cdc.gov/cmf-icd10.html on May 11, 2017 6:11:09 a.m.

[15] E.g. current status quo versus scenario with delayed SST.

The total births in a given period depend on the size of the population, its age structure and age- and state-specific fertility rates. Similarly, the number of deaths in any given period depends on the population size, the age distribution and age- and gender-specific mortality rates. In addition, net migration can lead to an increase in the population. More formally, the population of age a, gender g at time t is calculated as:

$$P_{s,a,g,t+1} = P_{s,a,g,t} + B_{s,a,g} - D_{s,a,g} + IM_{s,a,g} - OM_{s,a,g}$$

where $B_{s,a,g,t}$ represents the total births, $D_{s,a,g,t}$ total deaths. For example, a reduction in fatal motor vehicle crashes among adolescents would reduce the level of $D_{s,a,g,t}$ in the specific age group. $IM_{s,a,g}$ and $OM_{s,a,g}$ represent inward and outward migration respectively.[16]

Efficiency labor

In order to address the second component, the level of productivity θ is determined, which is essentially a combination of the level of educational attainment e and the corresponding wage level in the working-age population m. In order to determine both the current level of productivity at baseline θ and the level of productivity associated with a change in SST to 8:30 a.m., θ^*, we perform a set of different analytical steps and draw on a variety of different data sources.

In a first step, we derive the current educational attainment distribution using the proportion of high school dropouts (n), high school graduates (h) and college graduates (u) in each state by gender g, age a and ethnicity r, with data from the United States Census Bureau data.[17] The educational attainment data are not directly available for all gender–ethnicity–state combinations, unlike the overall population data, but for gender–ethnicity pairs and states separately. The two datasets are combined assuming that the differences across gender and ethnicity groups are independent by state but are jointly determined by the overall educational attainment in the given state.[18] The process is formally described in Appendix B.

In a second step, the level of productivity after the policy change, which is denoted as θ^*, is determined. To that end we draw on data derived in the first step on the distribution of educational attainment, as well as information on the distribution on average school start times in different states and information on the average income per age–state–gender–ethnicity combination. First, to determine the average change in sleep duration due to changes in SST, Δ, we use data on the distribution of SST for different U.S. states from the CDC (Wheaton et al., 2015). The school start times are provided in 30-minute intervals: before 7:30 a.m., 7:30–8:00 a.m., and 8:00–8:30 a.m. For simplicity, it is assumed that those intervals correspond to a starting time of 7:30 a.m., 7:45 a.m., and 8:15 a.m. and therefore a net average increase

[16] Approximate net migration rates per state have been derived using data from the U.S. Census Bureau: https://www.census.gov/data/tables/time-series/demo/geographic-mobility/state-to-state-migration.html

[17] United States Census Bureau (https://www.census.gov/data.html), 2015 population data. Hispanic refers to individual of any race of Hispanic origin. The "Other" category includes Asians, Native Americans and all other ethnicities.

[18] In other words, educational attainment of, for example, white males compared to white females is assumed to be the same in North and South Dakota – but educational attainment of white males in North Dakota compared to white males in south Dakota will follow the overall educational attainment across the whole population in those two states.

in sleep duration of 60, 45, and 15 minutes, respectively.[19] The calculated average net increase in sleep duration by state is reported in Appendix C.[20]

In line with Wang et al.'s (2016) findings on the non-linear effect of adolescent sleep on educational attainment, we assume that only students who get on average less than 7 hours of sleep per night, as compared to the recommended 8–10 hours, would benefit from the delay in SST. In order to derive the exposure–response relationship of the delay in the SST for students sleeping less than 7 hours, we need to determine the size of their population and their average amount of sleep at baseline. The proportions of students aged 12 to 19 sleeping less than 7 hours a night is from Keyes et al. (2015) and Eaton et al. (2010), which show that only about 32 per cent to 60 per cent of students get at least 7 hours of sleep per night, depending on their age. In order to determine the average sleep duration at baseline for students sleeping less than 7 hours a night, we draw on further granular information on the refined proportions of students sleeping less than 7 hours by McKnight-Eily et al. (2011). They report that about 6 per cent, 10 per cent, 23 per cent, and 30 per cent get on average ≤4, 5, 6, and 7 hours of sleep per night, respectively. To remain conservative in our estimates, we assume that in each of these groups, students slept exactly 4, 5, 6, and 7 hours, resulting in a weighted average of 6.12 hours of sleep per night for students who receive less than 7 hours of sleep per night on average.

Second, using the second order parameter estimates from Wang et al. (2016)[21] we derive the changes in the level of educational attainment e^* regarding high school dropouts (n), high school graduates (h) and college graduates (u) by a delay in SST in each state s by gender, and ethnicity group as follows:

$$e^{*n}_{s,g,r} = e^{n}_{s,g,r} - (e^{*h}_{s,g,r} - e^{h}_{s,g,r})$$

$$e^{*h}_{s,g,r} = \left[\, 0.086\Delta - 0.005 \cdot (2l\Delta + \Delta^2) + s^{h}_{s,g,r} \right] \cdot g^{h}_{s,g,r} - (e^{*u}_{s,g,r} - e^{u}_{s,g,r})$$

$$e^{*u}_{s,g,r} = \left[0.134\Delta - 0.009 \cdot (2l\Delta + \Delta^2) + s^{u}_{s,g,r}\right] \cdot g^{u}_{s,g,r}$$

where Δ represents the average increase in sleep duration per night as a result of later start times (see Appendix C), and where $s^{h}_{s,g,r}$ and $s^{u}_{s,g,r}$ represent the number of individuals that attended high school and university, respectively, whereas $g^{h}_{s,g,r}$ and $g^{u}_{s,g,r}$ represent the respective graduation rates (see Appendix B).

Finally, by bringing all previous steps together, the predicted change in educational attainment e^* induced by the policy change needs to be translated into future economic gains. To that end, we use information on the average earnings per highest educational attainment level collected by the Bureau of Labor Statistics.[22] In principle, we assume that higher educated individuals have, on average, higher levels of productivity θ, approximated using average earnings, and that productivity evolves over one's lifetime,

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[19] Note that the hypothetical policy scenario analyzed in this study assumes a universal state-wide shift of SST to 8:30 a.m. or later and hence we assume that schools which already start later than 8:30 a.m. would not move forward their start times.

[20] Note that overall 47 U.S. states are included in the analysis. The publicly available CDC data does not provide school start time distributions for District of Columbia and Maryland. In addition, average school start times in Alaska and North Dakota are later than 8.30 am.

[21] Table 3, column 3.

[22] https://www.bls.gov/emp/ep_chart_001.htm

using an age–productivity profile. However, we also need to reflect that the shift in SST would take several years to have a full impact as some students may only be exposed for a short period of time, and also due to a delay between when potential college attendees graduate and when they enter the labor market. To do this, we assume in the model – and consistent with the other data presented above – that the high school and college education takes four years to complete and that the effects estimated by Wang et al. (2016) decrease linearly for students exposed less than the full four years of the delay in SST. For instance, assuming that the policy would be implemented in the first year ($t = 0$), students graduating at the end of the first year ($t = 1$) would only see 25 per cent of the estimated effects of higher academic performance, students graduating at the end of the third year ($t = 2$) would be affected by 50 per cent and so on.[23] In addition, only students that do not pursue tertiary education would have an immediate impact on the labor market, whereas those students that go to college will only enter the labor market with a four years delay, albeit more likely with a higher entry salary. Hence, in the predictions of this model, the full effect of higher educational attainment associated with the delay in SST would emerge 8 years after the policy shift.

Putting all the pieces together, the total predicted relative change in productivity level θ for age a in state s is as follows:

$$\frac{\theta^*_{a,s}}{\theta_{a,s}} = \sum_{r\in R}\sum_{g\in G}\frac{e^{*n}_{s,g,r,a}}{e^{n}_{s,g,r,a}}\mu^n_{s,g,r,a}\frac{m^n_{g,r,a}}{m^n_a} + \sum_{r\in R}\sum_{g\in G}\frac{e^{*h}_{s,g,r,a}}{e^{h}_{s,g,r,a}}\mu^h_{s,g,r,a}\frac{m^h_{g,r,a}}{m^h_a} + \sum_{r\in R}\sum_{g\in G}\frac{e^{*u}_{s,g,r,a}}{e^{u}_{s,g,r,a}}\mu^u_{s,g,r,a}\frac{m^u_{g,r,a}}{m^u_a}$$

The average aggregate increase in productivity at any given point in time due to the delay in SST is a weighted sum of the relative changes in educational attainment of all individuals of the specific age a, gender g, ethnicity r, living in the given state s, weighted by the share of such individuals within the total population of the given age and education in that state $\mu_{s,g,r,a}$, multiplied by the relative average earnings of each group $m_{g,r,a}$ compared to the average earnings of all individuals with the same level of education of that age m_a. This aims to replicate heterogeneity of effects of educational attainment across different socio-economic population subgroups.

[23] Note this adjustment is essentially to make the estimates more conservative. The existing literature suggests that improvements in sleep duration improves the adverse outcomes of insufficient sleep already in a very short period of time (e.g. within a year).

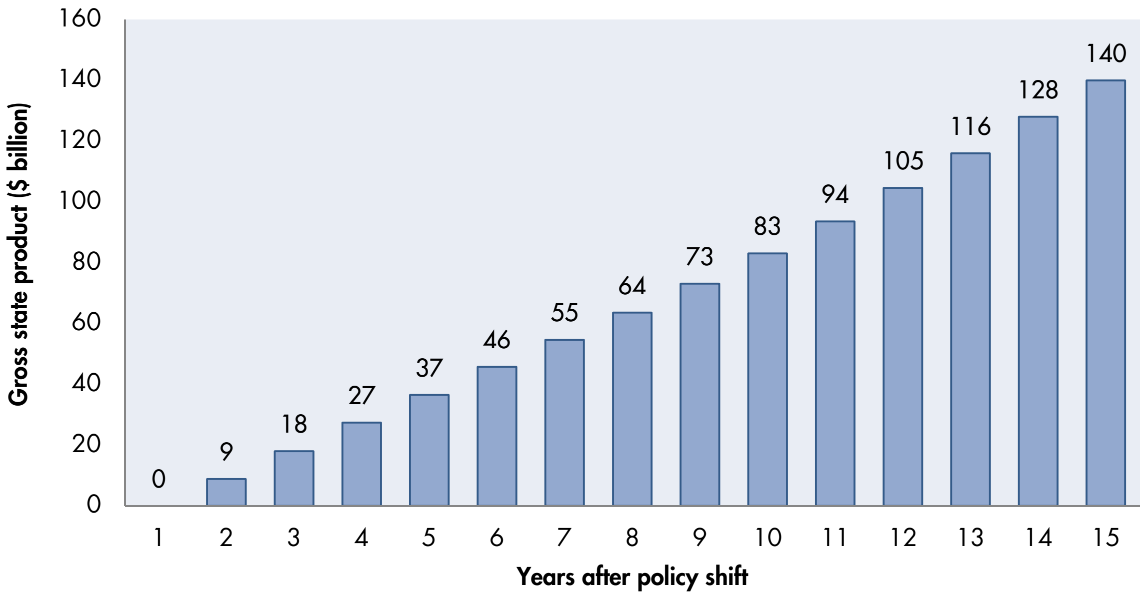
3. The economic implications of later school start times

This chapter presents the findings of the economic analysis from a statewide universal delay in SST to at least 8:30 a.m. First, the predicted cumulative gains in present values and their distribution across 47 U.S. states are reported. This is followed by a breakdown of the benefits by student and state. Finally, the overall benefits are compared to a set of different cost scenarios.

3.1. Cumulative economic gains from later school start times

This section illuminates the link between delayed SST and profound economic gains for 47 U.S. states. The economic gains are displayed as higher levels of economic output that would occur if SST would be delayed to 8:30 a.m. compared to the current distribution of SST (status quo). Economic output by state is measured in gross state product (GSP) terms.[24]

Figure 1: Predicted cumulative economic gains from delayed SST to 8:30 a.m.



Source: Authors' calculations.
Notes: The figure plots the predicted discounted cumulative gains (2016 $) of delayed SST to 8:30 a.m. in gross state product (GSP) terms, aggregated across 47 U.S. states.

[24] The gross state product is essentially the equivalent of gross domestic product (GDP) at the country level. https://www.bea.gov/regional/.

Figure 1 depicts the predicted cumulative economic gains from delayed SST in present-day value aggregated across the 47 U.S. states included in the analysis. In the first year of the shift in SST to 8:30 a.m., the model projects no immediate economic gains, given that the first cohort of students graduating from high school is only experiencing one-year of change in the SST policy before graduation. However, as more students will benefit in the future from the delayed start times as they enter the labor market, the findings suggest a gradual increase of economic gains over time. For instance, two years after the policy shift, the model projects a total economic gain of about $8.6 billion. This gain occurs in the form of increased aggregated gross state product, which represents about 0.04 per cent of current total U.S. gross domestic product. After five years, the predicted cumulative economic gain increases to about $37 billion, to $83 billion after ten years and to about $140 billion after fifteen years. On average, this corresponds to an annual economic gain of about $9.3 billion, aggregated across the 47 U.S. states, which is roughly the annual revenue of Major League Baseball (Brown, 2016).

The distribution of the cumulative economic gains across the different states over time is reported in Table 1, suggesting profound regional variation of the effects. Note that the variation of predicted gains across states is mainly driven by differences in the statewide initial average SST and underlying economic factors that also vary significantly by state (e.g. the industrial composition or average productivity levels). In absolute terms, larger states such as California would gain the most from a delay in SST to at least 8:30 a.m. For instance, after 2 years, it is predicted that California's GSP would be about $1.1 billion larger compared to the status quo. This is predicted to increase to about $17 billion after 15 years. In comparison, Florida would gain about $0.6 billion and Texas about $0.8 billion after 2 years and about $9 billion and $13 billion after 15 years, respectively.

Regarding the relative changes in per cent of current GSP, compared to the status quo, after 2 years the relative average gains from the policy change to later SST range from 0.01 per cent (Alabama) to 0.08 per cent (Massachusetts) of GSP. In year 10, the relative gains range from 0.16 per cent (Alabama) to 0.66 per cent (Delaware) of GSP. After 20 years, the gains range from 0.64 per cent (Alabama) to 1.58 per cent (Delaware).

Table 1: Predicted cumulative economic gain by state ($ million GSP)

	Years after policy change									
	2 years		*5 years*		*10 years*		*15 years*		*20 years*	
State	**$**	**%**	**$**	**%**	**$**	**%**	**$**	**%**	**$**	**%**
Alabama	11	0.01%	85	0.04%	328	0.16%	764	0.38%	1,277	0.64%
Arizona	189	0.07%	758	0.26%	1,683	0.58%	2,753	0.95%	3,855	1.33%
Arkansas	55	0.05%	264	0.22%	557	0.47%	978	0.82%	1,421	1.20%
California	1,106	0.04%	4,482	0.18%	10,229	0.41%	17,229	0.69%	24,849	0.99%
Colorado	155	0.05%	632	0.20%	1,516	0.48%	2,718	0.87%	3,960	1.26%
Connecticut	135	0.05%	574	0.23%	1,350	0.53%	2,304	0.91%	3,286	1.30%
Delaware	46	0.07%	193	0.28%	456	0.66%	773	1.13%	1,088	1.58%
Florida	641	0.07%	2,507	0.28%	5,544	0.62%	9,174	1.03%	12,858	1.45%
Georgia	257	0.05%	1,049	0.21%	2,373	0.48%	3,924	0.79%	5,572	1.12%
Hawaii	39	0.05%	186	0.23%	380	0.47%	613	0.76%	865	1.08%
Idaho	28	0.04%	115	0.18%	263	0.40%	440	0.67%	635	0.97%

	Years after policy change									
	2 years		*5 years*		*10 years*		*15 years*		*20 years*	
State	**$**	**%**	**$**	**%**	**$**	**%**	**$**	**%**	**$**	**%**
Illinois	261	0.03%	1,091	0.14%	2,559	0.33%	4,535	0.58%	6,753	0.87%
Indiana	153	0.05%	712	0.21%	1,579	0.47%	2,849	0.85%	4,170	1.24%
Iowa	98	0.06%	405	0.23%	917	0.53%	1,433	0.82%	1,988	1.14%
Kansas	59	0.04%	302	0.20%	636	0.42%	1,064	0.71%	1,530	1.02%
Kentucky	94	0.05%	516	0.27%	1,089	0.56%	1,760	0.91%	2,452	1.27%
Louisiana	120	0.05%	501	0.21%	1,176	0.49%	2,029	0.85%	2,917	1.22%
Maine	29	0.05%	121	0.21%	288	0.50%	494	0.86%	708	1.24%
Massachusetts	371	0.08%	1,419	0.29%	2,990	0.62%	4,769	0.98%	6,606	1.36%
Michigan	295	0.06%	1,218	0.26%	2,894	0.62%	4,794	1.02%	6,728	1.44%
Minnesota	188	0.06%	753	0.23%	1,772	0.54%	2,960	0.90%	4,200	1.28%
Mississippi	48	0.05%	233	0.22%	502	0.47%	846	0.80%	1,211	1.14%
Missouri	181	0.06%	740	0.25%	1,750	0.59%	3,115	1.06%	4,488	1.52%
Montana	26	0.06%	107	0.24%	229	0.51%	363	0.80%	505	1.12%
Nebraska	39	0.03%	164	0.15%	379	0.33%	654	0.58%	965	0.85%
Nevada	53	0.04%	219	0.16%	524	0.37%	919	0.66%	1,351	0.97%
New Hampshire	33	0.04%	156	0.21%	362	0.49%	628	0.85%	905	1.23%
New Jersey	385	0.07%	1,541	0.27%	3,568	0.63%	5,920	1.04%	8,297	1.46%
New Mexico	56	0.06%	222	0.24%	493	0.53%	786	0.84%	1,091	1.17%
New York	493	0.04%	2,077	0.15%	4,960	0.35%	8,847	0.63%	13,130	0.94%
North Carolina	263	0.05%	1,084	0.22%	2,469	0.50%	4,157	0.84%	5,926	1.20%
Ohio	435	0.07%	1,746	0.29%	3,724	0.61%	6,010	0.98%	8,360	1.37%
Oklahoma	104	0.06%	410	0.22%	914	0.49%	1,504	0.81%	2,132	1.15%
Oregon	83	0.04%	338	0.16%	778	0.36%	1,356	0.62%	1,999	0.92%
Pennsylvania	276	0.04%	1,213	0.17%	2,990	0.42%	5,387	0.76%	7,908	1.11%
Rhode Island	36	0.07%	164	0.29%	364	0.65%	592	1.06%	821	1.47%
South Carolina	130	0.06%	567	0.28%	1,254	0.62%	1,951	0.97%	2,677	1.33%
South Dakota	23	0.05%	101	0.21%	214	0.45%	346	0.73%	490	1.04%
Tennessee	120	0.04%	515	0.16%	1,219	0.39%	2,131	0.67%	3,122	0.99%
Texas	851	0.05%	3,412	0.21%	7,686	0.48%	12,835	0.80%	18,307	1.14%
Utah	68	0.05%	277	0.19%	691	0.47%	1,175	0.80%	1,679	1.14%
Vermont	17	0.06%	70	0.23%	159	0.53%	270	0.90%	385	1.28%
Virginia	330	0.07%	1,182	0.25%	2,650	0.55%	4,277	0.89%	5,975	1.24%
Washington	264	0.06%	1,214	0.27%	2,518	0.57%	4,031	0.91%	5,608	1.26%
West Virginia	38	0.05%	155	0.21%	362	0.49%	610	0.82%	871	1.17%
Wisconsin	152	0.05%	634	0.21%	1,511	0.50%	2,552	0.84%	3,642	1.21%
Wyoming	23	0.06%	99	0.25%	225	0.56%	378	0.95%	535	1.34%

Source: Authors' calculations.
Notes: The table reports the predicted discounted cumulative economic gains ($ million GSP) of delayed SST to 8:30 a.m. across all 47 U.S. states that would occur in years after the policy change, compared to status quo.

3.2. Economic benefits per student and benefit-cost ratios

The effects from delaying SST state-wide to at least 8:30 a.m. reported in Figure 1 and Table 1 suggest that even if a very conservative methodological approach is taken, the predicted economic benefits are substantial. However, in order to assess the effectiveness of the policy to delay SST, it is important to compare the economic benefits to their corresponding costs. To that end, this section provides an overview of the predicted economic gains per student across the 47 U.S. states and compares them against different cost scenarios in more detail.

3.2.1. The predicted economic benefits per student

Using the total number of students across U.S. middle and high-schools,[25] Table 2 reports the cumulative economic benefits per student after 2, 5, 10, 15 and 20 years, respectively.

Table 2: Predicted cumulative economic gain by state ($ per student)

	Years after policy change (gain $ per student)				
State	*2*	*5*	*10*	*15*	*20*
Alabama	31	246	953	2,220	3,712
Arizona	374	1,498	3,325	5,440	7,619
Arkansas	190	904	1,908	3,349	4,867
California	335	1,357	3,097	5,216	7,523
Colorado	294	1,199	2,876	5,158	7,515
Connecticut	517	2,209	5,193	8,863	12,639
Delaware	733	3,061	7,242	12,278	17,275
Florida	456	1,783	3,943	6,525	9,145
Georgia	269	1,098	2,485	4,109	5,835
Hawaii	476	2,295	4,688	7,553	10,653
Idaho	180	735	1,676	2,802	4,044
Illinois	259	1,082	2,539	4,499	6,700
Indiana	273	1,273	2,824	5,097	7,459
Iowa	395	1,625	3,681	5,756	7,983
Kansas	289	1,478	3,117	5,215	7,500
Kentucky	263	1,442	3,043	4,916	6,850
Louisiana	381	1,587	3,723	6,422	9,232
Maine	275	1,148	2,748	4,702	6,740
Massachusetts	704	2,693	5,673	9,050	12,535
Michigan	331	1,367	3,248	5,381	7,551
Minnesota	360	1,443	3,395	5,671	8,046
Mississippi	177	856	1,844	3,112	4,452
Missouri	341	1,396	3,302	5,877	8,468
Montana	338	1,366	2,942	4,656	6,473
Nebraska	258	1,096	2,527	4,358	6,433

[25] See Table 8 in Appendix C for the numbers of students and schools.

	Years after policy change (gain $ per student)				
State	*2*	*5*	*10*	*15*	*20*
Nevada	191	795	1,897	3,330	4,896
New Hampshire	286	1,343	3,117	5,416	7,801
New Jersey	551	2,207	5,112	8,482	11,886
New Mexico	373	1,469	3,268	5,204	7,226
New York	295	1,244	2,970	5,298	7,862
North Carolina	342	1,411	3,215	5,413	7,717
Ohio	410	1,646	3,510	5,665	7,879
Oklahoma	291	1,153	2,568	4,226	5,989
Oregon	294	1,198	2,758	4,810	7,088
Pennsylvania	276	1,212	2,987	5,381	7,900
Rhode Island	537	2,406	5,358	8,703	12,081
South Carolina	317	1,380	3,050	4,747	6,513
South Dakota	296	1,300	2,744	4,438	6,287
Tennessee	225	967	2,286	3,998	5,858
Texas	333	1,335	3,007	5,022	7,162
Utah	228	931	2,327	3,956	5,654
Vermont	365	1,523	3,464	5,876	8,365
Virginia	595	2,129	4,774	7,706	10,765
Washington	503	2,308	4,786	7,664	10,662
West Virginia	235	972	2,263	3,813	5,443
Wisconsin	360	1,498	3,572	6,034	8,610
Wyoming	461	1,982	4,497	7,553	10,702
Average	**346**	**1,461**	**3,309**	**5,552**	**7,906**

Source: Authors' calculations.
Notes: The table reports the predicted discounted cumulative economic gains per student of delayed SST to 8:30 a.m. across all 47 U.S. states, compared to the status quo with current distribution of SST.

On average, the predicted benefit per student across states after 2 years is $346, which is rising to $3,309 and $5,552 after 10 and 15 years, respectively. Similar to the predictions reported in Table 1, there is substantial variation across states. For instance, in Alabama the economic gain per student after 2 years is predicted to be about $31. This is significantly lower than the average of $346 per student across the 47 states. Other states with relatively low gains per student are Arkansas, Idaho and Mississippi (between $177 and $190 after 2 years). On the other hand, states such as Delaware and Massachusetts are predicted to proportionally gain more than $700 per student already after 2 years. Other states with relatively large gains per student are Connecticut, New Jersey, Ohio, Rhode Island and Wyoming.

The predictions presented in Table 2 depict the potential economic gains per student, but in order to make an assessment about the cost-effectiveness of the policy of later SST, the gains need to be compared against their corresponding costs.

3.3. The predicted benefit-cost ratios per student

Generally, the costs associated with delaying SST will vary by region and even by school district. The previous benefit–cost analysis by the Brookings Institution used a cost estimate of $150 per student per year, and we apply this figure as well. However, in order to illustrate a range of relevant cost scenarios which may apply for different regions and under different settings, we apply a set of scenarios denoted as "Normal", "High" and "Very High", and vary them by different type of costs, including annually reoccurring or upfront investment costs. The six different scenarios are outlined in Table 3.

Table 3: Cost scenarios applied in the analysis

Cost scenario:	Normal	High	Very High
(1): annual cost	$150 per student	$350 per student	$500 per student
(2): upfront + (1)	$110,000 per school	$220,000 per school	$330,000 per school

Notes: It is assumed that the occurring annual costs would capture costs in relation to changes in bussing strategies, whereas the upfront costs would capture the update of school infrastructure in relation to after-school activities. The cost per school is transformed into costs per student using data on the total number of students and schools provided in Table 8, Appendix C. The two variants of the "Normal" cost scenario mimic the general cost assumptions taken regarding costs of delaying SST from existing studies.

Each of the cost scenarios "Normal", "High" and "Very High" has two variants: (1) only annual costs per student apply; and (2) annual costs plus an upfront investment per school which aims to estimate costs for potential updates of school infrastructure related to after-school activities apply. For instance, in the "Normal" scenario, it is assumed that the annual costs per student are $150 and the upfront cost is an additional $110,000 per school. For the "High" and "Very High" scenarios, it is assumed that the upfront investment costs per school would double and triple in size, respectively. Note that the cost scenario "Normal" is using the cost estimates from previous studies (e.g. Jacob and Rockoff, 2011), whereas scenario "High" and "Very High" are projections intended to illustrate the potential impact of higher cost assumptions on the effectiveness of the policy to delay SST.

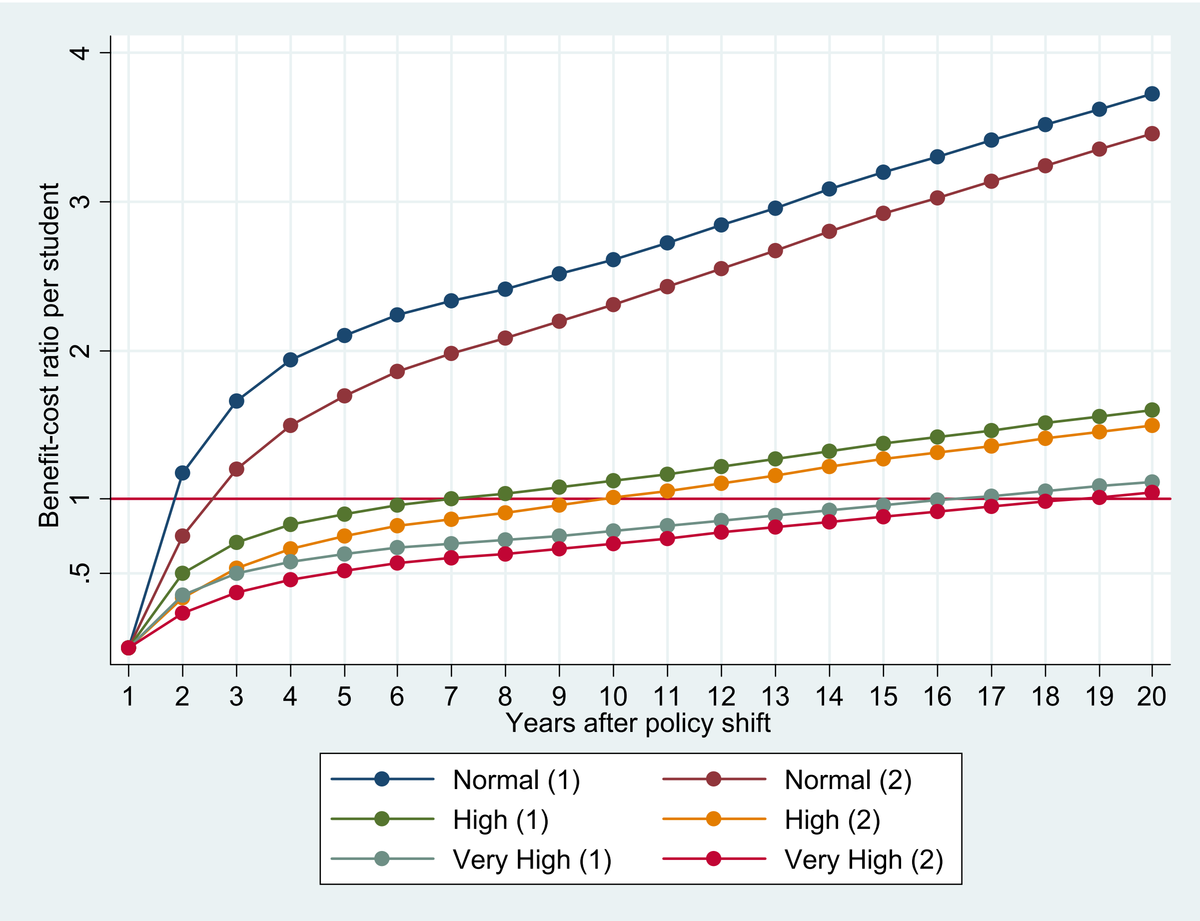
Accordingly, Figure 2 reports the benefit-cost ratio per student across the 47 U.S. states for the different cost scenarios.[26] Under the "Normal" scenario and the assumption that the costs per student are $150 per year in perpetuity and no upfront costs, the benefits are predicted to outweigh the costs per student (e.g. benefit–cost ratio is larger than 1) after 2 years of making the switch and delay SST to at least 8:30 a.m. After 13 years, the benefit–cost ratio would reach 3:1, meaning that every $1 invested would yield a return of $3. The ratio increases over time, reaching 3.5:1 just after 20 years. With upfront costs, the benefit will exceed the cost per student after 3 years and will reach a benefit-cost ratio of 3:1 after 16 years.

Under the "High" cost scenario, with a higher cost of $350 per student per year, the economic benefits from a universal statewide delay in SST to 8:30 a.m. is estimated to outweigh the cost between 6 and 7 years after the policy change, or 9 to 10 years if we assume upfront costs.

[26] Both benefits and costs per student are discounted and presented in present-day values. The future benefits and costs have been discounted by a rate of 4 per cent, which is common among the macroeconomic literature.

Under the "Very High" cost scenario, the costs per student per year are assumed to be $500 and upfront cost of $330,000. Remarkably, even under the assumption of extensive costs associated with delaying SST to at least 8:30 a.m., the predicted benefits are projected to outweigh the estimated costs between 16 and 18 years after the policy change, depending on whether upfront costs are taken into account or not.

Figure 2: Predicted benefit–cost ratio of delayed SST. (aggregated across 47 U.S. states)



Source: Authors' calculations.
Notes: The different cost scenarios "Normal", "High" and "Very High" are described in Table 3.

The projections presented in Figure 2 represent predicted figures aggregated across the 47 U.S. states, but Table 4 reveals significant state-by-state variation in the benefit-cost ratios. Specifically, Table 4 reports the predicted benefit–cost ratios for a delay in SST to at least 8:30 a.m. under the "Normal" cost scenario from 2 to 20 years after the policy change for the two variants (1) and (2). The findings suggest that in the vast majority of states, with the exception of Alabama, Idaho and Nevada, the predicted economic benefits for delaying SST would outweigh the costs within 5 years after the change (meaning that for every $1 spent the return is at least $1), independent of whether only annual costs or also upfront costs have been taken into account. The predicted benefit–cost ratio after two years varies from 0.11 (Alabama) to 2.39 (Massachusetts), which increases over time as more student cohorts will benefit from the change to later SST. After 10 years, on average, the benefit-cost ratio is between 2.31 and 2.62, meaning that for every $1 the return is more than double the initial investment.

Table 4: Predicted benefit–cost ratios by state ("Normal" cost scenario)

	Years after policy shift									
	2 years		*5 years*		*10 years*		*15 years*		*20 years*	
State	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Alabama	0.11	0.07	0.35	0.29	0.75	0.67	1.28	1.17	1.75	1.62
Arizona	1.27	0.81	2.16	1.74	2.63	2.32	3.14	2.86	3.59	3.33
Arkansas	0.65	0.41	1.30	1.05	1.51	1.33	1.93	1.76	2.30	2.13
California	1.14	0.73	1.95	1.58	2.45	2.16	3.01	2.74	3.55	3.29
Colorado	1.00	0.64	1.73	1.39	2.27	2.01	2.97	2.71	3.54	3.29
Connecticut	1.76	1.12	3.18	2.57	4.10	3.63	5.11	4.66	5.96	5.53
Delaware	2.49	1.59	4.41	3.56	5.72	5.06	7.08	6.46	8.15	7.56
Florida	1.55	0.99	2.57	2.07	3.12	2.75	3.76	3.43	4.31	4.00
Georgia	0.91	0.58	1.58	1.28	1.96	1.74	2.37	2.16	2.75	2.55
Hawaii	1.62	1.03	3.30	2.67	3.71	3.28	4.35	3.97	5.02	4.66
Idaho	0.61	0.39	1.06	0.85	1.32	1.17	1.62	1.47	1.91	1.77
Illinois	0.88	0.56	1.56	1.26	2.01	1.77	2.59	2.37	3.16	2.93
Indiana	0.93	0.59	1.83	1.48	2.23	1.97	2.94	2.68	3.52	3.26
Iowa	1.34	0.86	2.34	1.89	2.91	2.57	3.32	3.03	3.77	3.49
Kansas	0.98	0.63	2.13	1.72	2.46	2.18	3.01	2.74	3.54	3.28
Kentucky	0.89	0.57	2.08	1.68	2.40	2.13	2.83	2.59	3.23	3.00
Louisiana	1.29	0.83	2.29	1.84	2.94	2.60	3.70	3.38	4.35	4.04
Maine	0.93	0.60	1.65	1.33	2.17	1.92	2.71	2.47	3.18	2.95
Massachusetts	2.39	1.53	3.88	3.13	4.48	3.96	5.22	4.76	5.91	5.48
Michigan	1.12	0.72	1.97	1.59	2.57	2.27	3.10	2.83	3.56	3.30
Minnesota	1.22	0.78	2.08	1.68	2.68	2.37	3.27	2.98	3.80	3.52
Mississippi	0.60	0.38	1.23	1.00	1.46	1.29	1.79	1.64	2.10	1.95
Missouri	1.16	0.74	2.01	1.62	2.61	2.31	3.39	3.09	3.99	3.70
Montana	1.15	0.73	1.97	1.59	2.33	2.06	2.68	2.45	3.05	2.83
Nebraska	0.88	0.56	1.58	1.27	2.00	1.77	2.51	2.29	3.03	2.81
Nevada	0.65	0.41	1.14	0.92	1.50	1.33	1.92	1.75	2.31	2.14
New Hampshire	0.97	0.62	1.93	1.56	2.46	2.18	3.12	2.85	3.68	3.41
New Jersey	1.87	1.20	3.18	2.56	4.04	3.57	4.89	4.46	5.61	5.20
New Mexico	1.27	0.81	2.12	1.71	2.58	2.28	3.00	2.74	3.41	3.16
New York	1.00	0.64	1.79	1.45	2.35	2.07	3.05	2.79	3.71	3.44
North Carolina	1.16	0.74	2.03	1.64	2.54	2.25	3.12	2.85	3.64	3.38
Ohio	1.39	0.89	2.37	1.91	2.77	2.45	3.27	2.98	3.72	3.45
Oklahoma	0.99	0.63	1.66	1.34	2.03	1.79	2.44	2.22	2.82	2.62
Oregon	1.00	0.64	1.73	1.39	2.18	1.93	2.77	2.53	3.34	3.10
Pennsylvania	0.94	0.60	1.75	1.41	2.36	2.09	3.10	2.83	3.73	3.46
Rhode Island	1.83	1.17	3.46	2.80	4.23	3.74	5.02	4.58	5.70	5.28
South Carolina	1.08	0.69	1.99	1.60	2.41	2.13	2.74	2.50	3.07	2.85

State	2 years (1)	2 years (2)	5 years (1)	5 years (2)	10 years (1)	10 years (2)	15 years (1)	15 years (2)	20 years (1)	20 years (2)
	Years after policy shift									
South Dakota	1.01	0.64	1.87	1.51	2.17	1.92	2.56	2.34	2.97	2.75
Tennessee	0.76	0.49	1.39	1.12	1.81	1.60	2.31	2.10	2.76	2.56
Texas	1.13	0.72	1.92	1.55	2.38	2.10	2.90	2.64	3.38	3.13
Utah	0.77	0.50	1.34	1.08	1.84	1.63	2.28	2.08	2.67	2.47
Vermont	1.24	0.79	2.19	1.77	2.74	2.42	3.39	3.09	3.95	3.66
Virginia	2.02	1.29	3.07	2.47	3.77	3.34	4.44	4.05	5.08	4.71
Washington	1.71	1.09	3.32	2.68	3.78	3.34	4.42	4.03	5.03	4.66
West Virginia	0.80	0.51	1.40	1.13	1.79	1.58	2.20	2.01	2.57	2.38
Wisconsin	1.22	0.78	2.16	1.74	2.82	2.50	3.48	3.17	4.06	3.77
Wyoming	1.57	1.00	2.85	2.30	3.55	3.14	4.35	3.97	5.05	4.68
Average	**1.18**	**0.75**	**2.10**	**1.70**	**2.62**	**2.31**	**3.20**	**2.92**	**3.73**	**3.46**

Source: Authors' calculations.
Notes: Column (1) assumes cost of $150 per student per year and column (2) assumes that in addition to the $150 per student per year, each school has to invest $110,000 upfront for updates in school infrastructure related to after-school activities (e.g. update of lighting equipment).

From a policy perspective, these findings are important as they demonstrate that significant economic gains resulting from the delay in SST could accrue over a relatively short period of time following the adoption of the policy shift. In comparison, the Brookings Institution estimated a benefit–cost ratio of 9:1 per student, but calculated the benefits and costs over the working life of an individual, which is about 45 years on average, and hence the benefit-cost ratio cannot directly be compared to the ratios predicted in this study, which are year-on-year. However, if we apply the annual cost in perpetuity assumption of $150 per student per year to the Brookings Institution analysis (Jacob and Rockoff, 2011), which found that the overall lifetime gain of a student is $17,500 for a one-hour shift in SST, and further assume a 45 year time horizon, then the predicted adjusted benefit-cost ratio of the Brookings Institution analysis is approximately 6:1, instead of 9:1. By taking a more comprehensive and more detailed national approach, the figures presented in Table 4 suggest that after only 15 years (about a third of the working life of an individual), the benefit–cost ratio across the 47 states is about half of the benefit–cost ratio of the Brookings analysis. If the estimates reported in Table 4 would be extended to 45 years, the ratio would increase to about 7.5:1, which is about 1.2 times larger than the estimated adjusted benefit-cost ratio by Brookings Institution (of 6:1), even though the current analysis implies generally a net increase in SST of less than an hour (approximately 30 minutes).

In order to show the variation of the benefit–cost ratios under different cost assumptions, Table 5 reports the predicted benefit–cost ratios for the "High" cost scenario. In comparison to Table 4, the benefit–cost ratios in Table 5 are lower, as the assumed cost per student are higher. For instance, taking a cost of $350 per student per year and no upfront costs (variant 1), after two years two states would already reach a benefit-cost ratio of at least 1:1 (Delaware and Massachusetts). After 5 years more states would reach that threshold, and after 10 years, the majority of states would get every $ spent at least back in return. However, for Alabama, Idaho and Mississippi the predicted benefit-cost ratio under the "High" cost scenario would need longer to reach the 'break even' threshold, as they are not larger than 1 even after 20 years. Nevertheless, Table 5 reveals that even under a relatively high cost scenario, in the majority of states the policy change would pay off latest after 10 years, meaning that $1 spent would return at least $1.

Table 5: Predicted benefit–cost ratios by state ("High" cost scenario)

	Years after policy shift									
	2 years		5 years		10 years		15 years		20 years	
State	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Alabama	0.05	0.03	0.15	0.13	0.32	0.29	0.55	0.51	0.75	0.70
Arizona	0.54	0.37	0.92	0.77	1.13	1.01	1.34	1.24	1.54	1.44
Arkansas	0.28	0.19	0.56	0.46	0.65	0.58	0.83	0.76	1.00	0.94
California	0.49	0.33	0.84	0.70	1.05	0.94	1.29	1.19	1.52	1.43
Colorado	0.43	0.29	0.74	0.61	0.97	0.88	1.27	1.18	1.52	1.42
Connecticut	0.75	0.51	1.36	1.13	1.76	1.58	2.19	2.02	2.55	2.39
Delaware	1.07	0.72	1.89	1.57	2.45	2.20	3.03	2.80	3.49	3.27
Florida	0.66	0.45	1.10	0.91	1.34	1.20	1.61	1.49	1.85	1.73
Georgia	0.39	0.26	0.68	0.56	0.84	0.76	1.02	0.94	1.18	1.11
Hawaii	0.69	0.47	1.42	1.18	1.59	1.43	1.87	1.72	2.15	2.02
Idaho	0.26	0.18	0.45	0.38	0.57	0.51	0.69	0.64	0.82	0.77
Illinois	0.38	0.25	0.67	0.55	0.86	0.77	1.11	1.03	1.35	1.27
Indiana	0.40	0.27	0.79	0.65	0.96	0.86	1.26	1.16	1.51	1.41
Iowa	0.58	0.39	1.00	0.83	1.25	1.12	1.42	1.31	1.61	1.51
Kansas	0.42	0.28	0.91	0.76	1.06	0.95	1.29	1.19	1.52	1.42
Kentucky	0.38	0.26	0.89	0.74	1.03	0.93	1.21	1.12	1.38	1.30
Louisiana	0.55	0.37	0.98	0.81	1.26	1.13	1.59	1.47	1.87	1.75
Maine	0.40	0.27	0.71	0.59	0.93	0.84	1.16	1.07	1.36	1.28
Massachusetts	1.03	0.69	1.66	1.38	1.92	1.73	2.24	2.07	2.53	2.37
Michigan	0.48	0.32	0.84	0.70	1.10	0.99	1.33	1.23	1.53	1.43
Minnesota	0.52	0.35	0.89	0.74	1.15	1.03	1.40	1.30	1.63	1.52
Mississippi	0.26	0.17	0.53	0.44	0.62	0.56	0.77	0.71	0.90	0.84
Missouri	0.50	0.33	0.86	0.71	1.12	1.01	1.45	1.34	1.71	1.60
Montana	0.49	0.33	0.84	0.70	1.00	0.90	1.15	1.06	1.31	1.23
Nebraska	0.38	0.25	0.68	0.56	0.86	0.77	1.08	1.00	1.30	1.22
Nevada	0.28	0.19	0.49	0.41	0.64	0.58	0.82	0.76	1.00	0.95
New Hampshire	0.42	0.28	0.83	0.69	1.06	0.95	1.34	1.24	1.58	1.48
New Jersey	0.80	0.54	1.36	1.13	1.73	1.56	2.10	1.94	2.40	2.25
New Mexico	0.54	0.37	0.91	0.75	1.11	1.00	1.29	1.19	1.46	1.37
New York	0.43	0.29	0.77	0.64	1.01	0.90	1.31	1.21	1.59	1.49
North Carolina	0.50	0.34	0.87	0.72	1.09	0.98	1.34	1.24	1.56	1.46
Ohio	0.60	0.40	1.02	0.84	1.19	1.07	1.40	1.29	1.59	1.49
Oklahoma	0.42	0.29	0.71	0.59	0.87	0.78	1.04	0.97	1.21	1.13
Oregon	0.43	0.29	0.74	0.61	0.93	0.84	1.19	1.10	1.43	1.34
Pennsylvania	0.40	0.27	0.75	0.62	1.01	0.91	1.33	1.23	1.60	1.50
Rhode Island	0.78	0.53	1.48	1.23	1.81	1.63	2.15	1.99	2.44	2.29
South Carolina	0.46	0.31	0.85	0.71	1.03	0.93	1.17	1.08	1.32	1.23

	Years after policy shift									
	2 years		*5 years*		*10 years*		*15 years*		*20 years*	
State	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
South Dakota	0.43	0.29	0.80	0.67	0.93	0.84	1.10	1.01	1.27	1.19
Tennessee	0.33	0.22	0.60	0.50	0.77	0.70	0.99	0.91	1.18	1.11
Texas	0.49	0.33	0.82	0.68	1.02	0.92	1.24	1.15	1.45	1.36
Utah	0.33	0.22	0.57	0.48	0.79	0.71	0.98	0.90	1.14	1.07
Vermont	0.53	0.36	0.94	0.78	1.17	1.05	1.45	1.34	1.69	1.58
Virginia	0.87	0.58	1.31	1.09	1.62	1.45	1.90	1.76	2.18	2.04
Washington	0.73	0.49	1.42	1.18	1.62	1.46	1.89	1.75	2.16	2.02
West Virginia	0.34	0.23	0.60	0.50	0.77	0.69	0.94	0.87	1.10	1.03
Wisconsin	0.52	0.35	0.92	0.77	1.21	1.09	1.49	1.38	1.74	1.63
Wyoming	0.67	0.45	1.22	1.02	1.52	1.37	1.87	1.72	2.16	2.03
Average	**0.50**	**0.34**	**0.90**	**0.75**	**1.12**	**1.01**	**1.37**	**1.27**	**1.60**	**1.50**

Source: Authors' calculations.
Notes: Column (1) assumes cost of $350 per student per year and column (2) assumes that in addition to the $350 per student per year, each school has to invest $220,000 upfront for updates in school infrastructure related to after-school activities (e.g. update of lighting equipment).

Appendix D reports the breakdown by state of the predicted benefit–cost ratios for the "Very High" cost scenario. The findings suggest that even under the assumption of artificially set very high costs related to a delay in SST to 8:30 a.m., a handful of states would still break even after 10 years of the shift to later SST. After 20 years, it is predicted that the majority of states would have either reached the benefit-cost ratio threshold of 1 or would be very close to 1.

4. Summary and discussion

The current study illuminates the economic implications from a delay in later school start times across different states in the United States. This chapter summarizes and discusses the main findings.

4.1. Summary

The current study is the first to measure the economic gains associated with delaying school start times for different states across the U.S. Using a macroeconomic modeling approach, the findings suggest that delaying SST to at least 8:30 a.m. could lead to profound economic gains in the form of increased overall economic performance. Departing from the previous benefit–cost analysis provided by the Brookings Institution, this study takes into account the effect of later SST on academic performance and mortality from car crashes, and reports the estimated year-by-year and state-by-state changes the benefit-cost ratios from delaying SST. The study findings suggest that the economic benefits of delaying SST even by a relative short amount (approximately 30 minutes on average) would be large. For instance, by 2030, the predicted cumulative economic gain from delaying SST across the U.S. are about $116 billion, corresponding to a predicted annual average increase of $9.3 billion, which is roughly the annual revenue of the Major League Baseball. Examining the cost-effectiveness of the delay in SST, the benefit-cost ratios per student reveal that on average, and under a normal cost assumption, already between 2 to 3 years after the policy change, every $1 spent is paid back in estimated benefits. Specifically, after 5 years, for every $1 spent, the predicted national average return is between $1.7 and $2.1.

From a policy perspective, these findings are crucial as they demonstrate that profound economic gains could result from the delay in SST, which potentially already accrue over a relatively short period of time following the adoption of the policy shift. In comparison, the Brookings Institution estimated a benefit–cost ratio is 9:1, but calculated over the working life of an individual, which is about 45 years on average. By taking a more comprehensive and national approach, and assuming a relative shorter delay in SST (30 mins compared to 1 hour), the figures presented in this study suggest that after 45 years, the anticipated time an individual spends in the labor market until retirement, the predicted benefit-cost ratio would be even about 1.2 times larger.

Overall, it is important to stress that this study takes a conservative approach in only applying parameters in the calibration process of the model for which robust empirical evidence is available in the literature concerning the impact of sleep loss on affects adolescents' health and academic performance. Specifically, we utilized available data on car crash mortality and impaired academic performance. However, other potential impacts of insufficient sleep, such as the effects on mental health, including depression and suicide, or other potential negative effects related to obesity or other morbidities, that are also associated with negative impacts on the economy have not been taken into account. Hence, the reported benefits in this study are likely an underestimation of the full benefits related to delaying SST to at least 8:30 a.m.

On the cost side, this study uses a previous estimate of $150 per student per year and adds potential upfront investment costs of $110,000 per school to update infrastructure to accommodate after-school activities. In addition, in order to evaluate the robustness of the cost-effectiveness of the policy to delay SS, higher cost scenarios have been taken into account. Since costs will vary by school district, the costs applied in the current model serve for illustration purposes, but represent ostensible ranges. Furthermore, beyond increased transportation costs and other infrastructure investment cost, it is possible that there could be other costs that are not included in our model calculations, such as the costs that could incur for parents with having to go to work later or before or after school childcare and there could be a potential loss of income associated with a reduction in after school employment for adolescents. However, in our analysis, on average, the delay SST to 8:30 a.m. only reflected an average delay of 30 minutes. In reality, given that many schools start before 8 a.m., it is also possible that a greater "dose" of the intervention (i.e. more than a 30 minute change) could result in even greater benefits to outweigh the costs. Nevertheless, even if much higher cost estimates (e.g. $500 per student per year) are applied, which likely would cover some of these difficult to quantify additional potential costs to parents and the wider society, the benefits from delaying SST would still outweigh the costs after about twenty years. Moreover, in conjunction with the highly consistent and robust data showing the widespread consequences of adolescent sleep loss on health, safety, and academic performance (see e.g. Lowry et al. 2012 or Lytle et al. 2011), these benefit–cost projections suggest that delaying school start times is a cost-effective, population-level strategy that could have a significant impact on public health and the U.S. economy.

4.2. Discussion

These findings must be interpreted within the constraints of the study and the specific modeling approach. First, our model is a simulated or hypothetical "natural experiment" which presupposes a statewide universal shift in school start times to 8:30 a.m. or later. This presupposition may seem unjustified given that start times are generally determined at the local district level. However, there are several examples of proposed policy initiatives in states across the country, including a bill that recently has been discussed in the California state senate, which mandates that California middle and high schools start no earlier than 8:30 a.m.[27] Thus, the hypothetical policy shift modeled in the current analysis is potentially a conceivable strategy. Second, we focused on the benefit–costs ratios of later SST for the 47 states for which there was available data from the CDC on SST, and therefore do not have estimates for Maryland, District of Columbia, North Dakota, and Alaska. Third, the specific modeling approach taken in this study is in part based on assumptions that may influence the modeling outcome. It is important to emphasize that whenever an assumption had to be made, we aimed to make sure that the specific assumption would be conservative, hence leading to a potential underestimation of the potential true

[27] Senate Bill No. 328, California Legislature – 2017-2018 regular season. "An act to add Section 46148 to the Education Code, relating to pupil attendance." Published 26/04/2017.

effect. Finally, as mentioned, our model focuses on two specific factors that drive costs: the impact of sleep insufficiency on motor vehicle crashes mortality and academic achievement (i.e. high school and college graduation rates). These factors were chosen because we were able to derive robust estimates from the literature. However, as mentioned, there are numerous other costs associated with mental and physical morbidity that were not included in our model. For instance, the combined public health costs of the obesity epidemic in children and adolescents and its associated cardiovascular morbidities are estimated at $45 billion a year, and sleep loss is longitudinally associated with increased risk of obesity in children and adolescents (Magee et al., 2012). Further, insufficient sleep among teens is associated with an increased risk of engaging in property and violent crime (Umlauf et al., 2011). The direct and indirect costs of crime, including direct economic losses, increased insurance rates, loss of productivity, and various aspects of the criminal justice system, from police, to courts, to juvenile facilities and prisons, are estimated in the billions of dollars (NCJRS, 2000). In addition, the robust association between insufficient sleep and poor sleep quality and adolescent risk for mental health problems and other risk-taking behaviors, including substance use, could also contribute to substantial societal costs. Taken together, our estimates suggest substantial benefits relative to costs on a statewide basis related to a universal change in SST, and if anything, these estimates are likely conservative estimates of the true benefits.

In summary, it is important to put this economic data in context. The findings of this study, as well as the Brookings Institution findings, suggest that the benefits of later start times may outweigh the immediate costs. Moreover, when paired with the substantial literature demonstrating the dire public health consequences of insufficient sleep among adolescents, the multitude of health and academic benefits associated with later start times, and the lack of any scientific evidence to suggest that there are benefits to having teens start school earlier, these findings provide a strong case to counter the argument that changing school start times is too costly to endeavor. As policymakers, educators, and community members consider the challenges associated with implementing later start times, including the potential for upfront costs, it is important to balance these challenges, many of which may be short-term, with the potential for long-term return on investment in terms of public health and economic benefits.

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Appendix A: The overlapping generations model

Model description

The simulation model used in our study is an overlapping generations (OLG) model first introduced by Samuelson (1958) and Diamond (1965), and later developed by Auerbach and Kotlikoff (1987) who used simulated a pioneering large-scale numerical OLG model to evaluate fiscal policies. Unlike other models assuming all workers to be essentially equal, OLG model by definition assumes that the modeled economy is represented by people of different ages, which is necessary to capture effects of sleep deficiency through various means. Moreover, to allow for effects to differ across income groups, we further differentiate among workers in terms of their skill in a similar fashion to Heer and Maussner (2009) and Krueger and Ludwig (2013).

The economy has three sectors – households, firms, and government – which continuously interact on the markets just as in reality. Specifically, firms, representing the production sector, hire labor supplied by households to create output, paying wages in exchange for labor and interest rate as a cost of capital. In absence of international trade and public enterprises, all assets within the economy are ultimately in possession of people and they also constitute the final consumer of all production. The government collects income taxes from individuals and subsequently provides them with retirement benefits. We assume that the foreign trade effect is negligible as sleep deficiency has no direct influence on it and do not explicitly model foreign economies.

Households

Households and individuals are used interchangeably in the model and we only assume individuals aged 18+ in the economy (i.e. those that are economically active) in line with the related literature in order to decrease computation requirements. This will slightly underestimate the positive effect of later school starting times as individuals who would otherwise not graduate and start working will not be captured. However, given the overall high graduation rates, low human capital of high school dropouts and short time period, the number is negligible.

All people are assumed to live 60 years from the inception of their professional careers, out of which they spend $T = 44$ years working and $TR = 16$ in retirement, reflecting that the retirement age is set at 66 years in the U.S. and the average life expectancy is slightly over 80 years, according to the World Bank data. Since life expectancy in the model remains constant over the assumed period, retirement age also remains unchanged.

All individuals that end their education with at most a high school diploma are assumed to start working at the age of 18 in the model, while those with bachelor's degree are assumed to start working at the age of 22. The labor supply is exogenously set at 8 hours per workday for everyone. Besides the explicit modeling of differences in educational attainment, we model the differences in people's skillsets and other personal characteristics through determination of a labor-endowment distribution and its changes over time so that the ultimate distribution of labor output resembles what we can observe in reality. This can be understood also as a tool to model intra-generation wage distribution, including probability of being unemployed, ill, unable to work or, on the other hand, promoted or finding a better job. Specifically, we assume each individual is subject to an idiosyncratic productivity shock log-normally distributed with mean y_1 and variance σ_{y_1}. Over an individual's life, the idiosyncratic productivity shock z_t follows a Markov (AR(1)) process given by:

$$z_t = \rho z_{t-1} + \epsilon_t,$$

where $\epsilon_t \sim N(0, \sigma_\epsilon)$, and thus depends on its past realisations.

In order to approximate the autoregressive process, the continuum of all possible shocks must be limited; to do so, we follow Huggett (1996) and discretize the state space Z containing all shocks into nine realizations ranging from $-2\sigma_{y_1}$ to $2\sigma_{y_1}$. These realizations, in fact, constitute nine different income classes. The probability of having a given productivity shock can then be computed using integration over corresponding area under the normal distribution, and the efficiency index $e(z, t) = e^{z_t + \bar{y}_t}$, where t represents an agent's age and $\bar{y}_t$ is the mean log-normal income of t-aged workers, follows a finite Markov chain. Given wage w defined below, tax rate τ and labour supply n, the total annual salary I can then be calculated as:

$$I = (1 - \tau)\, e(z, t)\, w\, n.$$

Individuals within one cohort differ in their earnings in a way such that the resulting after tax Gini coefficient (a measure of statistical distribution of income) closely follows empirical data. We assume that the individual's productivity and earnings change over time, following the age–productivity profile reported by Hansen (1993). We assume that individuals may belong to any income class despite their education and that the change in school starting time – and the number of graduates – increases the aggregate productivity and wage levels rather than alters the wage distribution profile, adding more individuals in the higher income classes. This is principally due to the lack of detailed data on wage distribution of individuals per educational attainment level. Note that the shift in productivity differs by gender, ethnicity, state, and age, shifting the whole age–productivity profile.

During retirement, agents receive pension transfers from the government in a simplified social security framework where social security benefit repayment rates are based on a 35-year salary average (30-year in the model) and complemented by individual savings into pension funds.

Given a maximum life expectancy and certain death at that time, each year the remainder of the oldest cohort dies and a new generation is born. Population size in each age category is based on the population predictions described further. The model assumes no bequests implying that each worker starts with no wealth and, due to rational expectations, consumes all their remaining savings at the age of 60. However, all individuals also face a positive probability of death throughout their live, implicitly increasing their interest in immediate consumption rather than saving.

The lifetime utility function maximized by households operates with the standard constant relative-risk aversion (CRRA) function:

$$E_1\left[\sum_{t=1}^{T+TR} \beta^{t-1}\left(\prod_{j=1}^{t} s_j\right) u(c_t)\right],$$

$$u(c) = \frac{c^{1-1/\sigma_u}}{1-1/\sigma_u},$$

where σ_u is the intertemporal elasticity of substitution, $u(c)$ is the instantaneous utility function with consumption as its only parameter, s_j is the survival probabilities implicitly determined by population projections, and β is the discount factor determining time preference.

Finally, we assume that agents cannot borrow money and their consumption thus cannot exceed revenue, i.e. the sum of annual salary, pension payments (if retired), and one-year bond holdings earning risk-free interest rate r. The budget constraint is thus in general given by:

$$c_t = (1+r)k_{t-1} + (1-\tau)e(z,t)wn + pension - k_t.$$

Firms and government

Firms produce output using effective labor N and capital K, which are hired at wage w and interest rate r, equal to the marginal product of labour and capital, respectively, as determined within the competitive equilibrium framework (see below). Capital also depreciates at rate δ. Production is characterized by constant returns to scale and we assume the standard neoclassical Cobb–Douglas production function in form of:

$$Y = AK^{\alpha}L^{1-\alpha},$$

$$r = \alpha AK^{\alpha-1}L^{1-\alpha} - \delta,$$

$$w = (1-\alpha)AK^{\alpha}L^{-\alpha},$$

where A is the total factor productivity growth parameter denoting efficiency with which can the factors of production be used and α is capital output elasticity (capital share on production). Given the lack of multifactor productivity level data at the state level, we use the real GDP growth per state, multiplied by the ratio of multifactor productivity growth and real GDP growth at the aggregate US level, as a proxy. Note that the production function works with units of effective labor; wage and interest rate are then equal for all agents despite differences in their age and productivity group. The model assumes no inflation and all predicted changes to GDP are therefore in real terms.

The total factor productivity growth is assumed to be constant in all years; while not particularly realistic due to existence of business cycles and other external and internal disturbances, the constant value fits purposes of this study as we are mainly interested in output differences between the status quo and an optimal scenario. Arguably, lower labor productivity and output would also slightly diminish the total factor productivity growth in the long term; hence, our estimates are conservative as the potential difference would have been bigger in case of lower productivity growth in the status quo scenario.

The government has no active role in the economy and only collects taxes from individuals in exchange for future unilateral pension transfers. For simplicity, we assume that the taxes and pension system repayment rates (i.e. the ratio of retirement benefit to the average wage) remain constant over time as these have essentially no effect on our analysis.

General equilibrium

We assume the economy to be in equilibrium at all times, with all prices being simultaneously determined such that the market clearing conditions are met. Formally, for given initial distribution of capital $\{k_0^s\}_{s=1}^{T+TR}$, the set of value functions $V^s(k_t^s, K_t, N_t)$, individual policy rules $c^s(k_t^s, K_t, N_t)$, $n^s(k_t^s, K_t, N_t)$ and $k^s(k_t^s, K_t, N_t)$, and relative prices of labor and capital w_t and r_t, the equilibrium is such that:

1. Individual and aggregate behaviour are consistent:

$$N_t = \sum_{s=1}^{T} \frac{n_t^s}{T+TR}$$

$$K_t = \sum_{s=1}^{T+TR} \frac{k_t^s}{T+TR}$$

2. Households' dynamic programs and firms' optimisation problems are solved by satisfying the budget constraints using the relative prices w_t, r_t, pensions, and the individual policy rules:

$$c^s(.), n_t^s(.) \text{ and } k_{t+1}^s(.).$$

3. The goods market clears:

$$AK^\alpha L^{1-\alpha} = \sum_{s=1}^{T+TR} \frac{c_t^s}{T+TR} + K_{t+1} - (1-\delta)K_t.$$

We follow the approach from Nishiyama and Smetters (2007) and use value function iteration to compute agents' policy functions. Specifically, let $v(K)$ be the value function and let it be the discounted sum of all instantaneous utility functions $u(c_1), u(c_2), \ldots, u(c_{T+TR})$, where c_t denotes household's consumption at age t and K denotes the optimal capital decisions that maximise household's lifetime utility. Further, assume an optimal sequence of capital stocks from $t = 0$ to time $t = q$, i.e. $K = k_0, k_1, \ldots, k_q$. Then the best level of capital K^* in time $t = q + 1$ is given by:

$$v(K^*) = \max_{0 \le K' \le f(K)} u(f(K) - K') + \beta\, v(K'),$$

where $f(K)$ denotes the production function and $f(K) - K'$ thus denotes consumption in a given period. In case the value function is known, we may then compute the solution K^* using a policy function g, i.e.:

$$K^* = g(K)$$

Policy function thus represents the optimal decision regarding the next period level of capital as a function of the current capital stock.

Due to the presence of idiosyncratic shocks, policy functions cannot be computed from time $t = 0$ onwards because individuals do not know their future income and cannot plan consumption and savings accordingly. The algorithm therefore computes the policy functions retrospectively instead using backward induction, working iteratively from the set of initial assumptions.

Calibration parameters

Table 6: Model calibration parameters

Parameter	Value	Source
Share of students who get less than 7 hours of sleep per night	0.6	Keyes et al. (2015)
Average baseline amount of sleep	6.12	McKnight-Eily et al. (2011)
Average annual hours worked	1,765	Penn World Tables (v9)[28] Yamarik (2011)
Capital–labour ratio	0.6036	
Capital stock depreciation rate	0.0471	
Elasticity of intertemporal substitution	0.594	Havranek et al. (2015)
Gross Domestic Product (GDP); Gross State Product (GSP)	Various	Bureau of Economic Analysis[29]
Average real GDP growth rate (based on the 1997–2015 period)	Various	Bureau of Economic Analysis
Ratio of multifactor productivity and real GDP growth rates over the 1995–2014 period.	0.4361	OECD[30]
Wealth Gini coefficient	32.6	World Bank[31]

[28] http://www.rug.nl/research/ggdc/data/pwt

[29] https://www.bea.gov/regional/

[30] http://stats.oecd.org

[31] http://data.worldbank.org/indicator/SI.POV.GINI

Appendix B: Derivation of educational attainment data

As the data on educational attainment is not directly available for each state, gender and ethnicity combination, the data needs to be combined. More formally, the multivariate joint probability distribution of any individual having a certain level of education and being from state s, gender c, and ethnicity r is determined as:

$$e_{s,g,r} = e_{g,r} \cdot e_s,$$

where $e_{g,r}$ is the share of individuals of gender g and ethnicity r at the given educational attainment and e_s is the share of individuals at the given educational achievement in state s. Both data is available from the United States Census Bureau.[32] For the combination, we assume that the two marginal distributions are independent, i.e. that the educational attainment of white males relative to white females in North Dakota is the same as in South Dakota.

Further, note that educational attainment in a state is essentially a combination of the number of individuals that attended a given institution and the graduation rates. We may therefore calculate the proportions of high school dropouts (n), high school graduates (h) and college graduates (u) any missing, or $e^n_{s,g,e}$, high school $e^h_{s,g,e}$, and university education $e^u_{s,g,e}$, as:

$$e^n_{s,g,r} = 1 - e^h_{s,g,r}$$

$$e^h_{s,g,r} = s^h_{s,g,r} \cdot g^h_{s,g,r} - e^u_{s,g,r}$$

$$e^u_{s,g,r} = s^u_{s,g,r} \cdot g^u_{s,g,r}$$

where $s^h_{s,g,e}$ and $s^u_{s,g,e}$ represent the number of individuals that attended high school and university, respectively, whereas $g^h_{s,g,r}$ and $g^u_{s,g,r}$ represent the respective graduation rates. The data for graduation rates stem from different sources outlined below.

Table 7: Graduation rates

Variable	Granularity	Description	Source
High school graduation rate (2014–2015)	State, ethnicity	The share of students who graduate in 4 years with a regular high school diploma (as a percentage of all students in the class).	National Center for Education Statistics[33]
High school graduates	State/gender and ethnicity	Share of persons 25 to 29 years old with a regular high school diploma (as a percentage	United States Census Bureau. "2011-2015

[32] https://www.census.gov/data.html

[33] https://nces.ed.gov/ccd/tables/ACGR_RE_and_characteristics_2014-15.asp

Variable	Granularity	Description	Source
(2015)		of the total population of that age).	American Community Survey 5-Year Estimates", National Center for Education Statistics[34]
University graduation rate (2013)	State, gender, ethnicity	Percentage of students who graduated within 150 per cent of normal/expected time (as a share of all students in the program). Data for 4-year bachelor courses at state universities used as a proxy for the average graduation rates across all programs.	The Chronicle of Higher Education, College Completion information.[35]
University graduates (2015)	State, gender and ethnicity	Share of persons with a bachelor's degree (as a percentage of the total population).	United States Census Bureau. "2011–2015 American Community Survey 5-Year Estimates", National Center for Education Statistics

[34] https://nces.ed.gov/programs/digest/d15/tables/dt15_104.20.asp

[35] http://collegecompletion.chronicle.com/

Appendix C: Net increase in sleep length

Table 8: School information by state and increase in sleep length in the counterfactual scenario

Net increase in sleep length			
State	Nr of schools	Nr of students	Net increase in sleep length (mins)
Alabama	680	344,000	36
Arizona	860	506,000	24
Arkansas	450	292,000	23
California	3880	3,303,000	22
Colorado	730	527,000	33
Connecticut	380	260,000	40
Delaware	90	63,000	44
Florida	1570	1,406,000	26
Georgia	1030	955,000	22
Hawaii	280	81,154	28
Idaho	370	157,000	18
Illinois	1590	1,008,000	19
Indiana	740	559,000	28
Iowa	550	249,000	13
Kansas	540	204,000	24
Kentucky	710	358,000	25
Louisiana	630	316,000	48
Maine	240	105,000	34
Massachusetts	700	527,000	34
Michigan	1540	891,000	33
Minnesota	1100	522,000	16
Mississippi	570	272,000	40
Missouri	900	530,000	30
Montana	220	78,000	15
Nebraska	370	150,000	17
Nevada	260	276,000	33
New Hampshire	180	116,000	41
New Jersey	870	698,000	28
New Mexico	310	151,000	20
New York	2070	1,670,000	27
North Carolina	1120	768,000	25
Ohio	1640	1,061,000	35
Oklahoma	700	356,000	17

Oregon	480	282,000	19
Pennsylvania	1280	1,001,000	38
Rhode Island	100	68,000	37
South Carolina	500	411,000	25
South Dakota	230	78,000	15
Tennessee	760	533,000	29
Texas	3940	2,556,000	22
Utah	410	297,000	22
Vermont	100	46,000	25
Virginia	850	555,000	26
Washington	930	526,000	23
West Virginia	300	160,000	31
Wisconsin	860	423,000	29
Wyoming	130	50,000	27

Source: (Wheaton et al., 2015) and authors' calculations.
Notes: Net increase in average sleep time calculated using proportions schools in 3 start time intervals (before 7:30 a.m.; 7:30-8:00 a.m. and 8:00-8:30 a.m.. Information on number of schools and students for Hawaii obtained directly from Hawaii State Department of Education.

Appendix D: Benefit-cost ratios per student ("Very High" cost scenario)

Table 9: Benefit-cost ratios by state ("Very High" cost scenario)

	Years after policy shift									
	2 years		*5 years*		*10 years*		*15 years*		*20 years*	
State	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Alabama	0.03	0.02	0.11	0.09	0.23	0.20	0.38	0.35	0.53	0.49
Arizona	0.38	0.25	0.65	0.53	0.79	0.71	0.94	0.87	1.08	1.01
Arkansas	0.19	0.13	0.39	0.32	0.45	0.40	0.58	0.53	0.69	0.64
California	0.34	0.23	0.59	0.48	0.73	0.66	0.90	0.83	1.06	0.99
Colorado	0.30	0.20	0.52	0.43	0.68	0.61	0.89	0.82	1.06	0.99
Connecticut	0.53	0.35	0.95	0.79	1.23	1.10	1.53	1.41	1.79	1.67
Delaware	0.75	0.50	1.32	1.09	1.72	1.54	2.12	1.96	2.44	2.28
Florida	0.46	0.31	0.77	0.63	0.93	0.84	1.13	1.04	1.29	1.21
Georgia	0.27	0.18	0.47	0.39	0.59	0.53	0.71	0.65	0.83	0.77
Hawaii	0.49	0.32	0.99	0.82	1.11	0.99	1.31	1.20	1.51	1.41
Idaho	0.18	0.12	0.32	0.26	0.40	0.36	0.48	0.45	0.57	0.53
Illinois	0.26	0.18	0.47	0.38	0.60	0.54	0.78	0.72	0.95	0.89
Indiana	0.28	0.18	0.55	0.45	0.67	0.60	0.88	0.81	1.06	0.99
Iowa	0.40	0.27	0.70	0.58	0.87	0.78	1.00	0.92	1.13	1.06
Kansas	0.29	0.20	0.64	0.53	0.74	0.66	0.90	0.83	1.06	0.99
Kentucky	0.27	0.18	0.62	0.51	0.72	0.65	0.85	0.78	0.97	0.91
Louisiana	0.39	0.26	0.69	0.56	0.88	0.79	1.11	1.02	1.31	1.22
Maine	0.28	0.19	0.50	0.41	0.65	0.58	0.81	0.75	0.95	0.89
Massachusetts	0.72	0.48	1.16	0.96	1.35	1.20	1.57	1.44	1.77	1.66
Michigan	0.34	0.22	0.59	0.49	0.77	0.69	0.93	0.86	1.07	1.00
Minnesota	0.37	0.24	0.62	0.51	0.80	0.72	0.98	0.90	1.14	1.06
Mississippi	0.18	0.12	0.37	0.30	0.44	0.39	0.54	0.50	0.63	0.59
Missouri	0.35	0.23	0.60	0.50	0.78	0.70	1.02	0.94	1.20	1.12
Montana	0.34	0.23	0.59	0.49	0.70	0.62	0.81	0.74	0.92	0.86
Nebraska	0.26	0.17	0.47	0.39	0.60	0.54	0.75	0.69	0.91	0.85
Nevada	0.19	0.13	0.34	0.28	0.45	0.40	0.58	0.53	0.69	0.65
New Hampshire	0.29	0.19	0.58	0.48	0.74	0.66	0.94	0.86	1.10	1.03
New Jersey	0.56	0.37	0.95	0.78	1.21	1.08	1.47	1.35	1.68	1.57
New Mexico	0.38	0.25	0.63	0.52	0.77	0.69	0.90	0.83	1.02	0.96
New York	0.30	0.20	0.54	0.44	0.70	0.63	0.92	0.84	1.11	1.04
North Carolina	0.35	0.23	0.61	0.50	0.76	0.68	0.94	0.86	1.09	1.02
Ohio	0.42	0.28	0.71	0.59	0.83	0.74	0.98	0.90	1.11	1.04

State	2 years		5 years		10 years		15 years		20 years	
	Years after policy shift									
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Oklahoma	0.30	0.20	0.50	0.41	0.61	0.54	0.73	0.67	0.85	0.79
Oregon	0.30	0.20	0.52	0.43	0.65	0.58	0.83	0.77	1.00	0.94
Pennsylvania	0.28	0.19	0.52	0.43	0.71	0.63	0.93	0.86	1.12	1.04
Rhode Island	0.55	0.36	1.04	0.86	1.27	1.14	1.51	1.39	1.71	1.60
South Carolina	0.32	0.21	0.60	0.49	0.72	0.65	0.82	0.76	0.92	0.86
South Dakota	0.30	0.20	0.56	0.46	0.65	0.58	0.77	0.71	0.89	0.83
Tennessee	0.23	0.15	0.42	0.34	0.54	0.48	0.69	0.64	0.83	0.77
Texas	0.34	0.23	0.58	0.47	0.71	0.64	0.87	0.80	1.01	0.95
Utah	0.23	0.15	0.40	0.33	0.55	0.49	0.68	0.63	0.80	0.75
Vermont	0.37	0.25	0.66	0.54	0.82	0.73	1.02	0.94	1.18	1.11
Virginia	0.61	0.40	0.92	0.76	1.13	1.01	1.33	1.23	1.52	1.42
Washington	0.51	0.34	1.00	0.82	1.13	1.01	1.33	1.22	1.51	1.41
West Virginia	0.24	0.16	0.42	0.35	0.54	0.48	0.66	0.61	0.77	0.72
Wisconsin	0.37	0.24	0.65	0.53	0.85	0.76	1.04	0.96	1.22	1.14
Wyoming	0.47	0.31	0.86	0.70	1.07	0.95	1.31	1.20	1.51	1.41
Average	**0.35**	**0.23**	**0.63**	**0.52**	**0.78**	**0.70**	**0.96**	**0.88**	**1.12**	**1.05**

Source: Authors' calculations.

Notes: Column (1) assumes cost of $500 per student per year and column (2) assumes that in addition to the $500 per student per year, each school has to invest $330,000 upfront for updates in school infrastructure related to after-school activities (e.g. update of lighting equipment).