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Chapter V3 of
The HayWired Earthquake Scenario—Societal Consequences
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Chapter V3

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By Cynthia Kroll,[1] Shijia Bobby Lu,[2] Aksel Olsen,[3] and Anne Wein[4]

Abstract

This chapter uses existing modeling techniques that underlie the 2015 regional economic forecast of the San Francisco Bay region, California, to estimate how a major earthquake along the Hayward Fault would change the trajectory of that forecast. The Association of Bay Area Governments (ABAG) creates long-term regional forecasts of employment, population, and households that span a period of two to three decades. The forecast released in January 2015 is built on the framework of a Regional Economic Models, Inc. (REMI) model for the San Francisco Bay region and projects growth in the bay region through 2040. This chapter uses the simulation tools in the REMI model to apply the HayWired building damages from the HayWired scenario capital and output losses estimated using the Federal Emergency Management Agency's Hazus model to ABAG's economic and demographic 2015 regional forecast.

We apply Hazus estimates of direct output losses from a moment magnitude (M_w) 7.0 earthquake along the Hayward Fault to the REMI model, to examine direct, indirect, and induced effects on gross regional product (GRP), employment, and population. The analysis shows an economy that would experience substantial damages and losses in the short term. In the first year, employment would drop by almost half a million jobs, whereas GRP would decrease by 8 percent. The two counties near the epicenter of the earthquake would be greatly affected, with a 15 percent loss in jobs and 13 percent loss in GRP. Population losses because of the economic effect would be smaller—on the order of 150,000 (or 2 percent) in the first year, although previously reported analyses suggest that displacement within the region could be much higher, and social effects could lead to a larger outmigration than is indicated by the model. Much of the economy could recover within a few years, but a full return to the previous trajectory could take more than five years for the region and closer to a decade for the most severely affected counties. Recovery and rebuilding investments will be crucial to repairing the economic base of the region and returning it to its projected growth trajectory.

Sensitivity analyses using the model identify some of the critical factors that would lead to different levels of change. For example, a shortage of construction workers could lead to a deeper, longer recession as rebuilding is postponed. Should major technology employers decide to relocate substantial portions of their operations and later expansion outside of the region, the recovery period from the earthquake-induced recession could stretch to 6 or 7 years and the region's trajectory could be permanently damped relative to the ABAG 2015 forecast for 2040.

State and local policies, as well as business and personal preparedness can reduce the length and severity of effects. The model has substantial inbuilt resilience, whereas some of the sensitivity tests reduce that resilience and indicate how lack of advanced preparation and absence of relief spending and insurance after the fact could slow the region's trajectory in the long term.

Introduction

This chapter is a contribution to a broader set of analyses on the potential economic and social effects from a major earthquake on the Hayward Fault in the east bay subregion of the San Francisco Bay region, California. The chapter has a narrow purpose—to use existing modeling techniques that underlie the regional forecast of the San Francisco Bay region economy and population to estimate how a major earthquake would alter that forecast. Other chapters in this volume address community vulnerability (through application of past experience to existing demographic and social conditions; Johnson and others, Communities at Risk Overview and Population Movements chapters, in prep. [planned to be published as part of this volume]), the effects of the earthquake on the region's economic output during the first

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6 months after the earthquake (a computable general equilibrium analysis; Sue Wing and others, in prep. [planned to be published as part of this volume]), a detailed assessment of characteristics of businesses in vulnerable parts of the region (based on the National Establishment Time Series dataset; Wein, Haveman, and others, this volume), and an analysis of economic vulnerabilities at the neighborhood level in severely affected areas and the spread across neighborhoods related to commute flows within the most affected areas, between those areas, and in less-affected parts of the region (Wein, Belzer, and others, this volume).

This study applies the building damages from the HayWired scenario capital and output losses that are estimated from the Federal Emergency Management Agency's (FEMA) Hazus model to the Association of Bay Area Governments (ABAG) Regional Control Forecast using the Regional Economic Models, Inc. (REMI) model 1.7.8. The ABAG Regional Control Forecast is a forecast for the San Francisco Bay region created using the framework of the REMI model and adopted by the ABAG Executive Board in January 2015 as the basis for creating the projections used in Plan Bay Area 2040 (described by Kroll and others, 2017). The purpose of examining how an earthquake would change the REMI ABAG regional control outcome is to address several long-term questions on the economy that are not fully fleshed out in the short-term computable general equilibrium analysis (Sue Wing and others, in prep. [planned to be published as a part of this volume]), which focuses on immediate effects during the first six months. These long-term questions include:

1. What are the overall effects on economic output from the earthquake, taking into account the direct output losses from damage to buildings and contents (defined as furniture, equipment that is not integral with the structure, computers, and other supplies)? What are the effects on economic output from second-order multiplier effects from interrupted firms, capturing both upstream and downstream losses in output?

2. How do these losses in output affect employment by sector?

3. What are the population effects caused by changing workforce demand, changing price levels, and changing amenities in the region?

4. How does public and insurance spending affect the outcome of the earthquake recovery?

5. Would an earthquake of this magnitude be expected to change the long-term economic trajectory for the region in the future? Given uncertainties of predicting such effects, what types, levels, and duration of effects could lead to long-term negative or positive changes in the region?

The chapter begins with a brief discussion of the most relevant research on the long-term effects of natural disasters, especially research focused on urbanized areas in developed countries. A more in-depth review of disaster research is provided by Johnson and others (Long-Term Recovery, in prep. [planned to be published as a part of this volume]). We then lay the framework by briefly describing the REMI model, which is the basis for the San Francisco Bay regional forecast, and the Hazus model, which underlies the estimates of physical damage and direct output loss. We describe the analysis of the earthquake's economic effects by defining sequentially the measures of effect factors applied to the model and the results of each factor, followed by the measures of mitigation and policy approaches and the effects of those measures. We test the sensitivity of the results to the level of public spending, insurance coverage, construction costs, and potential relocation decisions of major employers. We conclude with an overview of findings, a discussion of how shifts in assumptions could change the results, and some policy observations.

What Past Experience Tells Us about Long-Term Effects of Natural Disasters

The past decade has seen an expansion of literature that focuses on the long-term effects of disaster. One such analysis is Hsiang and Jina (2014) that outlines four trajectories described in the literature of how a disaster may affect an economy in the long run. These trajectories are: "creative destruction," where the economy is stimulated by aid dollars and replacement investment; "build back better," where a short-term downturn is followed by a long-term "strengthening" and replacement capital is an improvement over older outmoded damaged capital; "recovery to trend," where economies converge back to the predisaster growth trend; and "no recovery," where the long-term growth is permanently reduced by diverted investment (Hsiang and Jina, 2014).

Research results to date offer mixed evidence on which of these trajectories an economy experiencing a natural disaster will follow and how effects may vary by geography, community, or country. DuPont and Noy (2015) conclude in a literature review that, "To summarize, the literature on the long-term impact of economic shocks is inconclusive, but the weight of the evidence suggests no long-term impact of even catastrophic shocks at the national level." They go on to note that, "Several papers, however, do point to some potentially long-term impacts at the local/regional level."

Methods of analysis to understand the long-term effects include statistical analyses across countries or within countries, across counties or metropolitan areas, case studies, and even more disaggregated analysis of the effects across individual households, establishments, or across simulation exercises of the type we conduct in this chapter. Economic effects examined include those on output (gross domestic or regional product) or income (total personal income), on employment, and effects on population movements. The widely diverse scales of inquiry, depth of detail, and indicators analyzed all lead to ambiguity in understanding the long-term implications of a natural disaster.

Cavallo and others (2013) constructed what they called “counterfactuals” to compare how economies experiencing natural disasters would have grown absent the event. They found that even economies experiencing large disasters (defined by lives lost relative to population size) have not experienced long-term lags in output growth relative to the estimations based on comparable areas of growth in a scenario without the event’s occurrence. Their research covered diverse disasters (“hydrometeorological,” geophysical, or biological), whereas Hsiang and Jina (2014) studied the effects of cyclones alone across countries. They conducted a statistical analysis based on number, timing, and size of events and found that, although an individual event has a marginally small effect on long-term output and income trajectory, because cyclones can occur in a single economy with some frequency, “…repeatedly exposing the same population to frequent storms results in an accumulation of income losses over time…” relative to what the economy would experience without cyclones (Hsiang and Jina, 2014).

Boustan and others (2017) investigated disaster effects on migration, poverty rates, and home prices in a study of all types of disasters across U.S. counties over a 90-year period. The results of the study suggest a direct relation between the level of outmigration and the number of disasters experienced, with a “super-severe” disaster doubling the overall average effect. Some variation of effects occurred by type of disaster. Poverty rates also increased, suggesting that wealthier households were better able to move after a disaster than were poorer households. Relief spending did not mitigate this effect and may have actually exacerbated outmigration by making it easier for households to move, whereas outmigration was particularly high where a severe event occurred in an area prone to disaster. Nevertheless, there was a great deal of variation in the propensity to migrate after a disaster. For example, higher outmigration occurred from rural areas than from productive urban areas. Earthquakes were not found to induce migration, in contrast to volcanoes, landslides, and fires (although it is not clear how landslides and fires induced by earthquakes affected the results). Housing prices were not sensitive to the frequency of disasters but did drop after a severe disaster.

Cavallo and Noy (2010), in their review of disaster research, note a differential level of impact between large and small countries. “Therefore, while direct losses may be high in large countries because of the wealth exposure, the greater capacity to absorb shocks means that indirect losses may be lower, and/or that the size of the damage may be lower relative to the size of the country” (Cavallo and Noy, 2010 p. 13). They also comment on “poverty traps,” which are related to restricted ability to recover owing to the lack of resources in poorer countries. A similar divide is found between rural and urban counties in recent research by Boustan and others (2017).

Retrospective studies of the case of Kobe, Japan, after the 1995 earthquake argue that, although the economy “recovered” (in the sense that would be applied to bouncing back from a recession, eventually exceeding pre-earthquake output and population), there were long-term changes in the level of growth and the structure of the economy after the earthquake. DuPont and Noy (2015) estimated how Kobe’s economy and population size would have grown had it maintained the same levels of these factors relative to other Japanese metropolitan areas in the post-earthquake period. Their analysis indicated that although the population returned to pre-earthquake trends within five years, gross domestic product (GDP) per capita, despite early fiscal stimulus spending, lagged by 13 percent of the synthetically constructed estimates of GDP for the metropolitan area absent an earthquake 15 years later.

Okuyama (2014) highlighted the variability of each disaster event and its effects on the economy. The author disaggregated elements of the Kobe economy before and after the earthquake and used a shift-share analysis to identify structural changes in the distribution of economic activity. Results indicated a decline in regional competitiveness, especially in final demand, more than ten years after the Kobe earthquake, attributed largely to the population decline that followed the earthquake. However, at the aggregate input-output level, many differences level out, suggesting that negative effects in one sector or one geographic area may be offset by positive effects elsewhere in the economy or country.

Simulation models are another approach to analyzing the potential or actual effects of a disaster and are generally applied to a single case study. Common analytic tools in these studies include computable general equilibrium (CGE) models, input-output (I-O) models, or, in some cases, the REMI model, which uses aspects of I-O, CGE, and other tools. Many are used for short-term analysis, as by Sue Wing and others (in prep., planned to be published as part of this volume). Xie and others (2014) used a CGE model to examine long-term effects of the 2008 Wenchuan earthquake in China. Their findings highlight the dependence of the outcome on what aspects of the disaster are included. Analyzing costs alone, without taking into account recovery investments, gives an unrealistic view of the outcome. Including recovery investment in the analysis brings long-term growth much closer to the expected trajectory absent the earthquake.

Several authors describe redistribution of activity in the absence of measurable long-term effects on a national or regional economy. The unevenness of effects may be geographic, with locational shifts in patterns of development, or through unevenness in the experience and recovery of different population groups within the region. Peacock and others (2014) examined long-term housing recovery after hurricanes in 1992 and 2008. They discovered that low-income areas (and, in one case, areas with high shares of minority populations) were more vulnerable to the initial-level damage experienced and recovered more slowly. In one case, the recovery differential disappeared after two years, whereas, in the second case, the differential continued for a longer time period. If effects are separated by owner-occupied and rental property, rental values continue to lag in recovery compared to homeowner values and compared to the prestorm values for at least four years. Tierney (1997) found that after the 1994 earthquake in Northridge, California, businesses in the most heavily damaged areas were less likely to have recovered to pre-earthquake levels, even if the business itself experienced no building damage, suggesting that there could be long-term effects on the affected area beyond any short-term effects of damage.

The historical literature, then, points to four possible areas of effect that should be considered in the analysis:

1. How quickly does recovery occur in the regional economy and population base?
2. What are the possible long-term outcomes to the economy—does growth (or decline) occur at the same rate as before the earthquake?
3. Would the internal composition of the economy change relative to expected trends?
4. Would the geographic patterns of growth change as a result of the earthquake?

The HayWired Scenario

The HayWired earthquake scenario examines a hypothetical moment magnitude (M_w) 7.0 earthquake on the Hayward Fault, centered along the urban corridor of the eastern San Francisco Bay region (see Seligson and others, 2018, for a detailed description of the HayWired scenario). The mainshock triggers liquefaction and landslides, and is followed by fires, further slip of the fault, and a series of aftershocks. Seligson and others (2018) calculated building damage of multiple hazards of ground shaking, landslide, and liquefaction for the mainshock and aftershock sequence of the HayWired scenario using the Hazus model, which we refer to as the Hazus analysis hereafter when discussing results. Scawthorn (2018) estimated the potential addition of building damage (outside of the Hazus model) caused by post-earthquake fires. Using the integrated building damage data from Hazus by Seligson and others (2018) and the fire analysis by Scawthorn (2018), Johnson and others (Concentrated Damage, in prep. [planned to be published as part of this volume]) estimated that the earthquake could result in extensive or complete damage to more than 103,000 buildings (both residential and nonresidential) in the San Francisco Bay region, as well as to a much smaller number of structures in other parts of California. The most severe damage would be in Alameda County, where 16 percent of all residential buildings and 29 percent of nonresidential buildings would experience extensive or complete damage, and where approximately 82 percent of residential and 85 percent nonresidential building square footage would sustain some type of damage, ranging from slight to complete. In addition to structural, nonstructural, and contents damage to buildings, roadways, rail service, and power, water, gas, and communications utilities would also be damaged, and critical life-support services (health and education) housed in the buildings would be impeded as well. The time frame for restoration of these facilities and services could range from a few days to nearly a year for some roadways and as much as three years for the most severely damaged parts of the Bay Area Rapid Transit (BART) system. These damages and delays, in turn, may have ripple effects on the economy through disruption to households, commute flows, and operating capacity within businesses.

The Hazus model estimates the level of physical damage from multi-hazards caused by an earthquake, identifying different levels of damages and loss for distinct types of residential and nonresidential buildings, as discussed in more detail elsewhere in the report by Seligson and others (2018). In financial terms, direct building and contents losses resulting from the mainshock, aftershocks, liquefaction, and landslides in the Hazus analysis are estimated to be $72 billion in 2016 dollars (table 1). Fire-caused building and content losses approach an additional $30 billion in 2016 dollars (Scawthorn, 2018). Fire damage would likely be covered by insurance rather than the damage directly related to seismic causes, although there would still be cases of underinsurance. Until these capital losses are repaired or replaced, these direct effects to buildings and contents mean considerable disruption to economic activity.

Taking into account building cleanup, repair, and recovery time, and the probability of recapturing some business-related loss after the event, as defined in the Hazus technical manual (see FEMA [2003] and Sue Wing and others [in prep., planned to be published as a part of this volume] for a more detailed discussion), integrated building damage data from the mainshock, landslides, liquefaction, aftershocks, and fire effects translates into direct output loss estimates of $27.0 billion (2016 U.S. dollars) for all affected counties. Output loss estimated for Alameda County amounts to $17.5 billion and for the nine-county bay region to $26.9 billion, or 8 and 3 percent of total output, respectively. Effects from fire following the mainshock alone account for $2.2 billion of the loss to the bay region, whereas $500 million of the output loss results from aftershocks. Of aftershock-related output losses, 80 percent ($397 million) is concentrated in Santa Clara County (table 2).

On the basis of estimates of residential building damage from ground shaking and liquefaction, Seligson and others

Table 1. Hazus-estimated direct building and contents value effects from the HayWired scenario in the San Francisco Bay region, California.

[Amounts are in billions of 2016 U.S. dollars for damages from the mainshock, aftershocks, liquefaction, and landslides. Loss data generated from Seligson and others (2018). Note that these numbers do not include the additional loss caused by fire]

County	Nonresidential buildings	Residential buildings	Building contents	Total direct loss
Alameda	11.3	15.4	7.0	33.7
Contra Costa	2.7	5.1	2.0	9.8
Marin	0.3	0.8	0.3	1.4
Napa	0.03	0.05	0.03	0.11
San Francisco	1.2	1.4	0.7	3.3
San Mateo	1.5	2.8	1.4	5.7
Santa Clara	5.1	7.6	4.3	17
Solano	0.1	0.2	0.1	0.4
Sonoma	0.03	0.18	0.05	0.26
San Francisco Bay region total	22.3	33.5	15.8	71.6
Other areas	0.22	0.41	0.21	0.84

Table 2. Direct output loss for the HayWired scenario in the San Francisco Bay region, California.

[Values in millions of 2016 U.S. dollars]

County	Mainshock, landslides, liquefaction	Mainshock, landslides, liquefaction, and fire after earthquake	Mainshock, landslides, liquefaction, fire after earthquake, and aftershocks
Alameda	16,136	17,447	17,489
Contra Costa	2,764	2,949	2,951
Marin	115	220	220
Merced	1	1	1
Monterey	6	6	6
Napa	9	10	10
Sacramento	2	2	2
San Benito	7	7	7
San Francisco	726	743	746
San Joaquin	47	47	47
San Mateo	759	854	910
Santa Clara	3,533	3,994	4,391
Santa Cruz	18	18	19
Solano	58	129	129
Sonoma	8	10	10
Stanislaus	14	14	14
Yolo	1	1	1
Total[1]	24,206	26,452	26,956
San Francisco Bay region total[1]	24,110	26,356	26,858

[1]Because of rounding, sum totals may not be exact.

(2018) estimate that the displacement from the mainshock is about 153,000 households, and the population seeking short-term shelter would exceed 48,000 people. Building damage from aftershock ground shaking adds more than 2,800 displaced households, and 1,600 people seeking shelter. Johnson and others (Population Movements, in prep. [planned to be published as part of this volume]) argue that the potential population displacement and sheltering needs caused by damage from landslide, fire, lifeline infrastructure damage, and utility outages or environmental threats are not included in these estimates, and that displacement could be as high as 268,000 households and 720,000 people. According to Johnson and others (Population Displacement, in prep. [planned to be published as part of this volume]), the methodology used by Seligson and others (2018) for calculating short-term shelter requirements recognizes that only a portion of those displaced from their homes will seek public shelter, and some will seek shelter even though their residence may have low levels of damage.

The Hazus calculation for the HayWired scenario is based on a 2005–2006 inventory of buildings. Housing stock expanded by 9.8 percent in Alameda County and 7.4 percent region-wide between 2005 and 2017. New construction is more likely to be resistant to shaking and liquefaction and possibly less vulnerable to fire as well, potentially reducing the share of buildings and contents vulnerable to damage and displacement effects.

The ABAG Regional Control Forecast and the REMI Model

Beginning in the fall of 2014, ABAG used a REMI model as a framework for producing a regional forecast for the nine counties that compose the San Francisco Bay region (Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Sonoma, and Solano). The model divides the San Francisco Bay region into four subregions, as shown in table 3 and figure 1. A final regional forecast adopted by the ABAG executive board in February 2016 (Association of Bay Area Governments Planning and Research Department, 2016) serves as the benchmark comparison forecast for the HayWired REMI analysis (see Kroll and others, 2017, for an explanation of the regional forecast; appendixes 1–5 describe the methodology for producing the ABAG Regional Control Forecast). Absent a major earthquake or other disruptive event, the region is projected to experience a slowdown of growth compared to the very rapid post-recession expansion of 2010–2015, and to maintain its competitive advantage in such sectors as professional and business services and some aspects of the information sector. To do so, the region will need to add almost 700,000 jobs and almost 2 million people

Table 3. California's San Francisco Bay subregions and the counties that compose them.

Subregions	Counties
North bay	Napa, Solano, and Sonoma
East bay	Alameda and Contra Costa
South bay	Santa Clara
West bay	Marin, San Francisco, and San Mateo

between 2015 and 2040. The forecast—9.6 million people and 4.7 million jobs in the region by 2040—has a policy or visionary aspect because it assumes the region's housing needs are successfully addressed, so that existing and in-migrating workers will be able to find housing in the region and in-commuting would be kept to a minimum. A major earthquake would certainly disrupt the housing expectations implied in the ABAG Regional Control Forecast in the short run because the model measures relative real estate prices rather than number of units. The pace of the housing market and transportation network recovery could have long-term effects depending on how both businesses and individuals react to this disruption.

Regional Economic Models, Inc. (2015) describes the version of the model used in this analysis (p. 3):

> PI+ is a structural economic forecasting and policy analysis model. It integrates input-output, computable general equilibrium, econometric, and economic geography methodologies. The model is dynamic, with forecasts and simulations generated on an annual basis and behavioral responses to compensation, price, and other economic factors.
>
> The model consists of thousands of simultaneous equations with a structure that is relatively straightforward. The exact number of equations used varies depending on the extent of industry, demographic, demand, and other detail in the specific model being used. The overall structure of the model can be summarized in five major blocks: (1) Output and Demand, (2) Labor and Capital Demand, (3) Population and Labor Supply, (4) Compensation, Prices, and Costs, and (5) Market Shares.

The model captures economically significant relations, such as that between productivity in an industry and associated demand for labor, while taking into account the available labor supply in the region and its cost relative to other regions. The population, in turn, grows through natural increase as well as through economic migration when earnings rise to compensate for the cost-of-living differential. With the basic parameters of the economy and its responses estimated, the model allows the analyst to test the effects of specific occurrences to see

Figure 1. Map showing the four subregions in the Association of Bay Area Governments (ABAG) REMI model version 1.78 of the San Francisco Bay region, California. REMI refers to models produced by Regional Economic Models, Inc.

how the system responds given the change. Direct, and some indirect, effects of an event (such as an earthquake) are added in the policy change part of the model to evaluate how the event affects different aspects of the economy, including the direct and indirect effects on output, employment, population, and labor force. The flexible aspects of the model allow sensitivity testing on the level of effects, some aspects of mitigation and resilience (such as telework), alternative government actions (such as imposed outmigration), and social effects (such as changing perceptions toward the attractiveness of the region). Some of these are included in our application of the model. One caveat is that the level of the effects result from assumptions about factors such as the degree of outmigration or government spending, which ultimately rely on judgment calls by the analyst. Furthermore, to the degree that the model is built for times of ordinary economic relations rather than prolonged crisis, such as long-term recovery stresses from a major earthquake, it could underestimate or misallocate the level or location of the effect.

The ABAG REMI model includes four subregions: the east, north, west, and south bay (table 3) as well as a fifth “region,” the rest of California. The strongest effects are felt in the east bay, with some effects spreading to the other bay subregions. Some neighboring counties to the east also experience small effects (capital and output losses) according to the Hazus results, but these are difficult to discern in the San Francisco Bay region REMI model v. 1.7.8 because of the aggregation with the rest of the State. Therefore, discussion of the REMI model results will focus on the four subregions within the larger San Francisco Bay region. Rather than basing the analysis on the standard regional control built into the model, employment and population effects are examined relative to the ABAG Regional Control Forecast, which becomes the baseline forecast absent an earthquake.

Hypothetical Sequence of Effects and Their Incorporation into REMI

We follow the approach adopted by Rose and others (2009; a study of border closure effects on the U.S. economy), where a set of possible drivers of change is identified, the effect of each driver is examined separately, and then a combination of factors is used to examine cumulative and interactive effects. We first describe conceptually the factors causing economic change. We then identify factors in the REMI model that represent these changes. We follow with independent application of the different types of change and finally with the combination of some of these factors to look at overall effects. For some factors, the absolute measure of change is a straightforward application of Hazus results. For other factors, the level of change requires judgment informed by past experience. We include some analyses at the end of the chapter to test the sensitivity of results to some of these assumptions.

A major earthquake will disrupt the economy through the initial physical losses, human casualties inflicted on the region, and the disruption to business output and employment from the damage, which we refer to as direct effects. However, the effects quickly become more complex, because indirect effects, listed below, arise and may continue even as recovery efforts begin.

- As production halts in damaged space, suppliers to affected businesses experience drops in demand, whereas those dependent on the output of damaged businesses will face shortages or rising costs.
- Damage to utilities, such as power and water, may cause business operations to cease temporarily, even in undamaged buildings.
- Damage to road and transit networks can disrupt supply chains and employee commutes between work and home, as well as tourism, business-related travel, and shipments (including supply chains) from within and beyond the region.
- Seaport and airport damage can disrupt supply and customer networks.
- Housing damage may incapacitate employees and customers in the short term and can lead to an outmigration of workers and customers in the long term.
- Shortages in supplies and available labor may lead to higher production costs.
- Coping with loss and disruption may decrease productivity of workers.
- “Reputation” effects can spread beyond the immediate effects of damage, as visitors or potential new residents avoid the region because of expectations of problems.

Yet there are stimulating effects as well:

- The rebuilding period can bring a boom to some industries and occupations, and rebuilding can leave behind a newer capital stock than what was damaged.
- Insurance payments and government spending can cover some of the costs of response, repair, and recovery.
- The influx of rescue and recovery workers can fill hospitality services that would otherwise have declined because of loss of business and leisure travel caused by the earthquake and its aftermath.

There are additional responses that may bring either positive effects, leading to resilience, or enhance negative effects:

- The high level of technological sophistication in the local economy can have both short-term resilience effects and long-term depressing effects on growth.
    - Businesses that make heavy use of portable computers, cloud-based files and services, and wireless communications may be able to continue operating despite displacing effects of local building damage. Demand for their services may even increase if they can substitute for more location-bound operations.
    - However, these operating characteristics may enable the business to be footloose, and to move divisions to other locations outside the region. Given anticipated temporary cost spikes and attendant operational disadvantages, temporary relocation from the region could evolve into permanent relocation of operations beyond the bay region.
- Insurance and government payments need to be paid for. The effects on the region will vary depending on whether the cost is tied directly to the affected area, the bay region, or spread more widely to the State or Nation.
- Businesses, government, and nonprofit organizations may be able to relocate to space that is still usable and also to provide help to one another, mitigating the effects of damage and displacement. For example, temporary agreements to share space can keep businesses in operation, reduce operating costs from displacement, and provide continuity of services, making the economy more resilient.

The next section describes how these effects and response measures are included in the REMI model.

Assumptions and Simulated Effects within the REMI Model—Part 1

To estimate how the effects of the HayWired scenario would affect the San Francisco Bay region's economy, we used the regional control scenario in the REMI model from the Plan Bay Area 2040 regional forecast and then entered measures of effects into the model. The model reports the effects of these changes over the forecast period. The model forecast goes from 2010 through 2040 in annual increments, with the HayWired scenario effects examined between 2018 and 2040.

The major earthquake effects applied to the bay region REMI model regional forecast consisted of output loss from building damage, output loss from transportation disruption, changes in housing prices, and migration decisions. After applying the effects that create losses in the economy (described in detail below), we also added the stimulating effects of recovery efforts to the model. Response, repair, and reinvestment in capital stock stimulates new economic activity to counterbalance some of the losses and to support a return to predisaster levels. We looked at government spending in the analysis to assess the overall effects of the earthquake on the economy after the expenditure of resources for rebuilding and recovery. The effects of the earthquake are reported in terms of total output change (the direct effects from damage plus secondary and tertiary effects from supply-chain disruption and business and population relocation), employment, and population change.

Direct Output Loss from Building Damage

Whereas the REMI model includes residential and nonresidential capital stock and capital investment variables, the stock variables are not directly related to output in the model. Thus, entering a loss in capital stock becomes only stimulating as the model accounts for rebuilding, without accounting for the output loss tied to the capital stock. For this reason, we began with entering output losses estimated directly from Hazus into the REMI model.

Direct output loss occurs when building damage disrupts economic activity. In the Hazus model, this is the product of floor area, output realized per square foot, and the expected days of loss of function for each damage state. Recapture factors, factors discounting the business-related output loss from earthquakes owing to the possibility that some of the loss could be recouped to some extent by working overtime after the event, are also taken into account in the Hazus output calculations (see Sue Wing and others, in prep. [planned to be published as a part of this volume] for a more disaggregated analysis of direct and recaptured effects). Total Hazus-estimated output loss (table 2) was disaggregated into loss for a 3-year time period to reflect the time needed for rebuilding that causes output loss to last longer than 1 year. In the HayWired scenario, a series of aftershocks follow the mainshock over the course of 2 years. Although the largest four aftershocks hypothetically happen in 2018, two of which occur 2 weeks after the mainshock and the other two occur about 6 months later, direct output loss from all sequences of aftershocks in this analysis were added into the second-year total. This captures the spread through time of effects of larger aftershocks that occur near the end of 2018, so that most of the output loss occurs in 2019.

Overall, the estimated direct output loss from building damage (from the mainshock, aftershocks, and fire following earthquake effects) for the bay region is around $26 billion in the first year, $580 million in the second year, and $22 million in the third year (in 2016 dollars) after the earthquake (table 4). The east bay subregion of the San Francisco Bay region accounts for the majority of the loss: $20 billion in the first year, and $105 million and $18 million in the following two years, respectively.

Table 4. Direct output loss estimates from Hazus as defined in the REMI Association of Bay Area Governments model for the HayWired scenario shown by subregion of the San Francisco Bay region, California.

[Subregions are defined in table 3. REMI refers to the models produced by Regional Economic Models, Inc. Data sourced from the Association of Bay Area Governments and Metropolitan Transportation Commission from Hazus results. There is no estimate for total output for the State of California from Hazus. n.a., not applicable]

Subregion	1st year, in millions of 2016 dollars	2d year, in millions of 2016 dollars	3d year, in millions of 2016 dollars	1st year loss of area's output, in percent
East bay	20,317	105	18	7.1
North bay	147	2	1	0.1
West bay	1,809	67	1	0.7
South bay	3,984	405	2	1.8
San Francisco Bay region total[1]	26,257	579	22	3.0
Rest of California	96	2	0	0.0
California total[1]	26,354	581	22	n.a.

[1]Because of rounding, sum totals may not be exact.

The level of loss by sector was determined by the type of building the sector occupies, the degree of damage to that occupancy type, and total employment and output levels of the industry. We calculated the share of output loss for each industry using Hazus output loss results by occupancy class through the North American Industry Classification System (NAICS) (appendix 1, table 1.1) and the crosswalk between Hazus occupancy class and REMI industry (table 1.2) and applied those shares to the total output estimates in 2018 of the REMI regional control scenario in the version of the model used for Plan Bay Area 2040. This leads to slightly different total output loss estimates, because the baseline in the two models are different. We also found that five industry sectors—telecommunications; performing arts and spectator sports; museum, historical sites, zoos and parks; amusement, gambling, and recreation; and food services and drinking places—belong to the same occupancy class. However, utility providers report shorter estimated recovery times than the Hazus default value. Therefore, for the telecommunication sector, we revised the loss of function time for damage state and recaptured factor for damage state to recalculate a lower level of output loss. The results are shown in appendix 1.

Among all 66 private nonfarm industries, the petroleum and coal products manufacturing industry experienced the largest value of output loss ($2 billion, 4 percent of the industry's total output) in the San Francisco Bay region in the first year, followed by food services and drinking places ($1.9 billion, 9 percent), ambulatory health care services ($1.8 billion, 6 percent), machinery manufacturing ($1.6 billion, 12 percent), real estate ($1.3 billion, 1 percent), and professional, scientific, and technical services ($1.2 billion, 1 percent). Several manufacturing sectors sustained the largest share of industry output loss, including 22 percent of motor vehicles, bodies and trailers, and parts manufacturing; 16 percent of paper manufacturing, and 12 percent of machinery manufacturing. In the second year, total output loss declined for the bay region. The largest amount of output loss was in ambulatory health services ($90 million), food services and drinking places ($77 million), and private hospitals ($72 million). In the third year, output loss, although very small, only remained in the social assistance and nursing and the residential care facilities sectors, because they are more dependent upon the reconstruction of buildings (table 1.3). Loss by occupancy class is translated to loss by REMI industry sector. See appendix 1 for further discussion regarding translation methodology.

Jobs, as reported by REMI, are measured by the Bureau of Economic Analysis (BEA) and represent an annual total, which includes not only wage employment but also self-employment, rather than a monthly average of wage and salaried employment only, as reported by the Bureau of Labor Statistics (BLS). The BEA employment total is about 26 percent higher than the BLS total for the San Francisco Bay region. Percentages are reported here to show the relative effects, whatever employment base is used. We reduced the forecast industry output in the REMI model Plan Bay Area 2040 regional control by the industry-specific loss and examined the cumulative effects of how such reductions reverberated throughout the economy. Direct output loss from building damage led to a loss of 232,000 jobs in 2018, and a 50,000 person decline in population related to job loss, or 4.6 percent of total jobs and 0.6 percent of population. Population displacement related to damage to residential buildings was almost 15 times this level, according to Seligson and others (2018) and Johnson and others (Population Movements, in prep. [planned to be published as part of this volume]). However, displacement from a home does not necessarily mean displacement from the region. The population analysis is discussed as a separate category below.

Job losses in the east bay subregion of the San Francisco Bay region are estimated to be 160,000, more than two thirds of the region's total loss, and 10.5 percent of total jobs in the east bay subregion (table 5). The north bay, west bay, and south bay subregions of the San Francisco Bay region experience reductions of 8,000, 33,000 and 33,000 in employment (1.4, 2.0, and 2.5 percent), respectively. The direct population effects of job loss for the east bay subregion

Table 5. Estimate of 2018 employment and population effects in the San Francisco Bay region, California, relative to Association of Bay Area Governments forecast levels from Hazus-estimated output loss related to HayWired scenario building damage.

[Subregions are defined in table 3. Data generated using the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model; analysis of the HayWired scenario from 2018 (this study)]

Subregion	Employment loss	Employment loss as a percent of subregion's job base	Employment loss as a percent of total loss	Population loss attributed to job loss	Population loss as a percent of area population	Population loss as a percent of total loss
East bay	158,872	10.5	68	36,243	1.3	72
North bay	7,623	1.3	3	2,856	0.3	6
West bay	32,585	2.0	14	5,527	0.3	11
South bay	33,212	2.5	14	5,495	0.3	11
San Francisco Bay region total[1]	232,293	4.6	100	50,121	0.6	100

[1]Because of rounding, sum totals may not be exact.

are a drop of 1.3 percent in 2018, accounting for more than 70 percent of the region's direct job-related loss in population (table 6). The other three subregions are estimated to lose 14,000 people in the first year related to job loss, a much smaller share of their populations. In the second year, bay region job levels are 19,000 less than the projected levels without the earthquake, and population is lower by 41,000 people, which are 0.4 percent of employment level projected for the region in REMI and 0.5 percent of the projected population level.

The industry with the largest employment loss in the first year is food services and drinking places, with a loss of about 34,000 jobs (11 percent). The construction sector loses approximately 19,000 jobs (7 percent), which would create challenges for the region as construction activities will be needed for the recovery of communities. Large losses in employment in critical neighborhood-serving retail trade and ambulatory health care services sectors would also make the recovery work harder for cities and communities (table 7). Because of multiplier effects, total output loss of all private nonfarm sectors is approximately $46 billion in 2018 (2016 dollars), compared with the $27 billion direct output loss estimated by Hazus. The real estate sector has the largest output loss ($4 billion), followed by professional services and construction sectors, both of which sustain a loss of more than $3 billion in industry output in year 2018 (table 8; appendix 2).

Table 6. Estimate of 2019 employment and population effects in the San Francisco Bay region, California, relative to Association of Bay Area Governments forecast levels from Hazus-estimated output loss related to HayWired scenario building damage.

[Subregions are defined in table 3. Data generated using the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model; analysis of the HayWired scenario from 2018 (this study)]

Subregion	Employment loss	Employment loss, in percent	Employment loss as a percent of total loss	Population loss	Population loss as a percent of area population	Population loss as a percent of total loss
East bay	8,850	0.6	47	29,192	1.1	71
North bay	1,195	0.2	6	2,547	0.2	6
West bay	2,982	0.2	16	4,627	0.2	11
South bay	5,500	0.4	30	4,746	0.2	12
San Francisco Bay region	18,527	0.4	100	41,112	0.5	100

Table 7. Ten industries with the largest estimated reduction of employment from the HayWired scenario owing to building, population, and other output losses identified in linked industries in the San Francisco Bay region, California, in 2018, relative to the Association of Bay Area Governments forecast.

[Data generated using the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model; analysis from 2018 (this study)]

Category	Job loss	Share of job loss, in percent
Food services and drinking places	33,603	10.90
Construction	18,576	7.30
Retail trade	17,555	4.20
Professional, scientific, and technical services	16,643	2.50
Ambulatory health care services	14,464	8.10
Administrative and support services	12,984	4.20
Social assistance	9,775	4.50
Performing arts and spectator sports	8,225	13.60
Real estate	7,564	3.00
Hospitals	7,370	6.80

Table 8. Ten industries with the largest estimated total cumulative output loss from the HayWired scenario owing to building, population, and other output losses identified in linked industries in the San Francisco Bay region, California, in 2018, relative to the Association of Bay Area Governments forecast.

[Data generated using the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model; analysis from 2018 (this study)]

Category	Output loss	Share of output loss, in percent
Real estate	4,095.15	2.9
Professional, scientific, and technical services	3,304.39	2.3
Construction	3,053.06	7.5
Ambulatory health care services	2,625.5	8.5
Petroleum and coal products manufacturing	2,485.79	5.2
Food services and drinking places	2,315.74	10.4
Retail trade	1,958.74	4.0
Wholesale trade	1,897.34	4.0
Machinery manufacturing	1,830.1	13.9
Monetary authorities and other credit institutions	1,694.08	3.8

Transportation Network and Commuting Flows

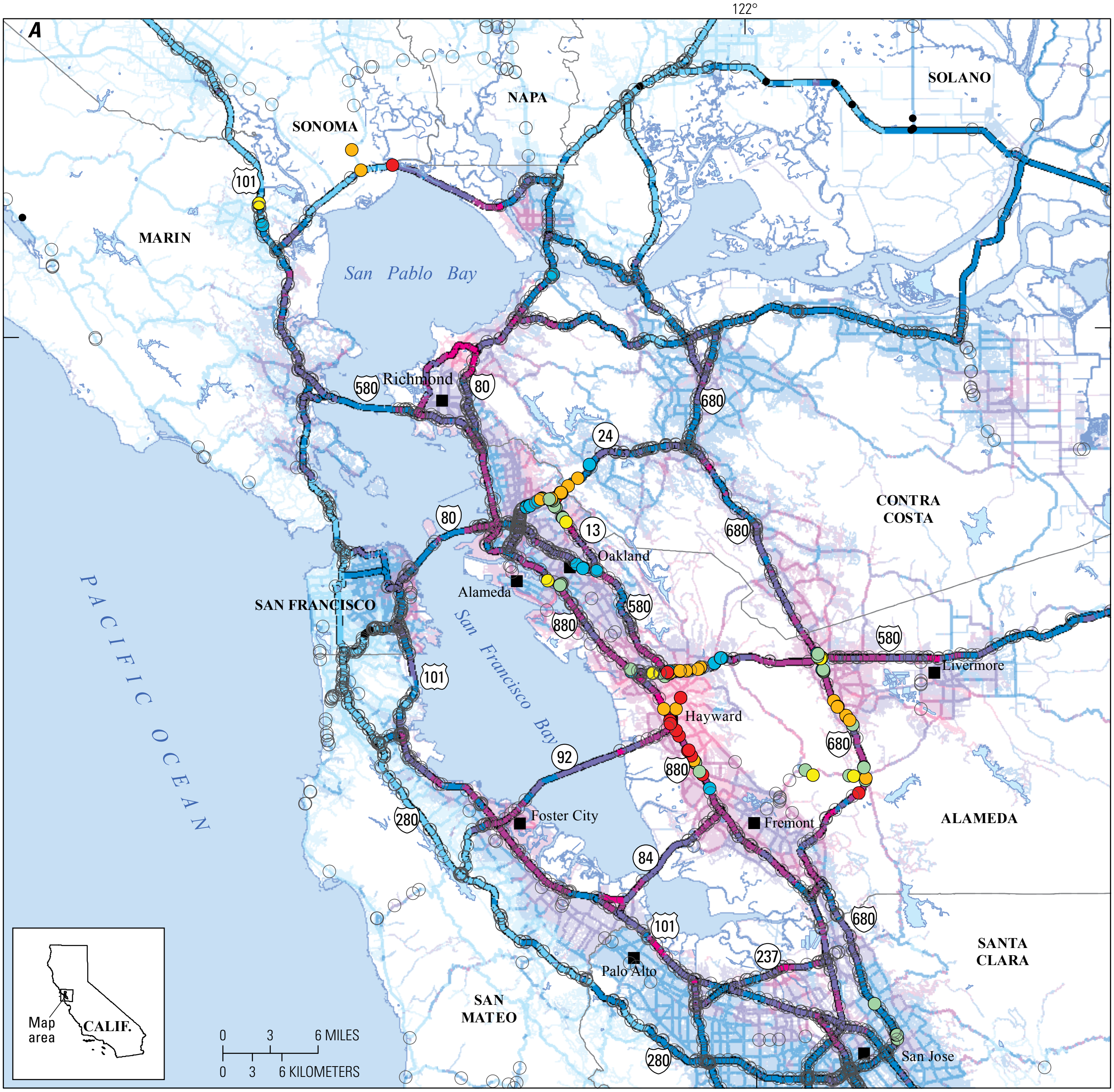
The transportation network provides important lifeline support to a functional economy. After an earthquake, recovery of the region's economy, housing, and communities depends on the restoration of the transportation system. Even if buildings are relatively intact, as long as the workers cannot get to their place of work, business activities will not be able to recover. Jones and others (this volume) identify the potential damages to major transportation systems in the region, including the road network and regional transit systems, such as the BART system. Figure 2 shows the range of repair times for shaking damage to the California Department of Transportation (Caltrans) roadway bridges and BART facilities.

Roadway damage would occur on major freeways and State highways, most of which require 2 to 3 weeks to repair. Severe damage is expected to happen along Interstates 880 and 580 near San Leandro and Hayward, along Interstate 680 in the Dublin-Pleasanton area, along Highway 24 in northern Oakland, and along Highway 37 near Sears Point between Novato and Vallejo, for which the repair time ranges from 4 to 10 months.

The effects on commuter flow, in addition to worksite buildings being damaged, can lead to further adverse effects on the regional economy. Wein, Belzer, and others (this volume), in an analysis of commuter flows within the region from or to areas with concentrated damage (census tracts with 20 percent or more extensive or complete damage to overall building square footage), found that commuting flows could affect the regional economy beyond the immediate damages from the earthquake. We examined commuting flow effects for both the areas with concentrated damage and those outside of heavily affected areas, which we refer to as "less-affected areas" hereafter (figs. 2, 3).

Damage to the transportation infrastructure system interrupts worker commute patterns and can increase the business output loss. After the 1989 Loma Prieta, Calif., earthquake, commuter transportation disruption (caused by a one-month closure of the San Francisco-Oakland Bay Bridge, in particular) was largely averted by alternative roadway routes and switching modes to the BART system and ferries (Deakin, 1991). Commutes were as much as 15 minutes longer, and limited relief was obtained from changes in work schedules or alternate workplaces (including home). After the 1994 Northridge earthquake damaged four major freeways in the Los Angeles area, Boarnet (1998) reported that 31 percent of employees (in surveyed businesses) endured longer commutes for 1 or 2 months on average (depending on the level of effect). Gordon and others (1998) estimated that increased travel time cost commuters at least $33 million. The most common employer policy allowed employees to change their work hours (Boarnet, 1998). More than twenty years later, San Francisco Bay region commuters are able to leverage technological advancements and are already responding to everyday traffic congestion with work-at-home options. However, the damage to the system is likely to be much greater than from the 1989 Loma Prieta earthquake, and repairs may last much longer. To incorporate the effects of transportation network and commute flow disruptions in the REMI analysis, we looked at where workers work and live by industry at the detailed census-tract level and at where roadway and freeway bridge damage would heavily affect workers' commutes. We differentiate the level of effect by the type of economic activity, to the extent such information is available, recognizing that flexibility to work at home varies by sector and occupation.

The U.S. Geological Survey (USGS), using Hazus, estimated that extensively or completely damaged buildings in commercial and industrial occupancy classes could lose functionality from a week to a year (FEMA, 2003). Regional roadways and bridges experiencing downtime could be repaired within 2 to 40 weeks (on the basis of calculations by Werner and others, 2000). Given the uncertainty of repair times for extensively or completely damaged buildings and roadways, we assume that the direct output loss for the heavily affected areas calculated using the Hazus methodology by USGS has accounted for the commuting flow effects in these areas, since those who work in heavily affected areas would not be commuting to buildings and areas that are nonfunctional. On the other hand, in less-affected areas, building repair times would be shorter. Likewise, if the transportation network is still broken, regardless of residence locations, commuters would not be able to get to buildings in these areas, leading to additional business output losses.



Hydrology from U.S. Geological Survey National Hydrography Dataset, 2016
Boundary data from U.S. Census Bureau TIGER data, 2016
Universal Transverse Mercator zone 10 north projection
North American Datum of 1983

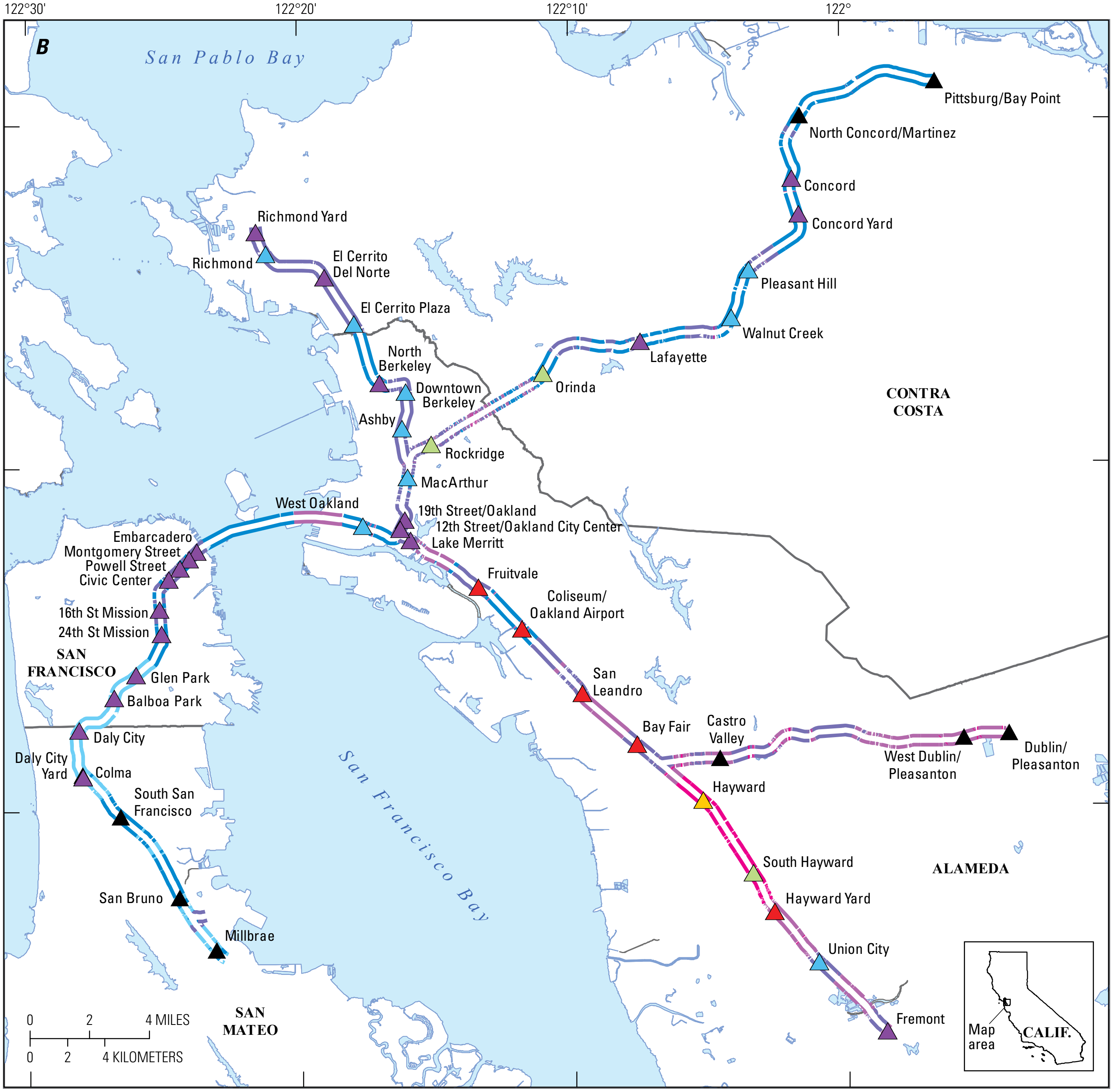
EXPLANATION

Transportation network

Surface street — Secondary street — Highway — **Multi-hazard exposure**
- Low
- Moderate
- Moderate-high
- High
- Very high

Highway bridge repair time
- 4 to 10 months
- 3 to 6 months
- 5 to 12 weeks
- 4 to 8 weeks
- 2.5 to 6 weeks
- 2 to 3 weeks
- None

Figure 2 (pages 13–14). Maps of the San Francisco Bay region, California, showing the multi-hazard exposure of roadways (*A*) and the Bay Area Rapid Transit (BART) system rail lines (*B*), including the estimated repair times for California Department of Transportation bridges and BART facilities in the HayWired scenario. Multi-hazard exposure refers to the combined shaking, landslide, liquefaction, slip, and fire hazards that follow the hypothetical earthquake of the HayWired scenario. Map modified from Jones and others (this volume).



Hydrology from U.S. Geological Survey National Hydrography Dataset, 2016
Boundary data from U.S. Census Bureau TIGER data, 2016
Universal Transverse Mercator zone 10 north projection
North American Datum of 1983

EXPLANATION

BART rail multi-hazard exposure
- Low
- Moderate
- Moderate-high
- High
- Very high

BART station repair time range
- 1 to 3 years
- 9 to 12 months
- 2 to 36 weeks
- 1 to 14 days
- <1 day
- New station; not analyzed

Figure 2 (pages 13–14).—Continued.

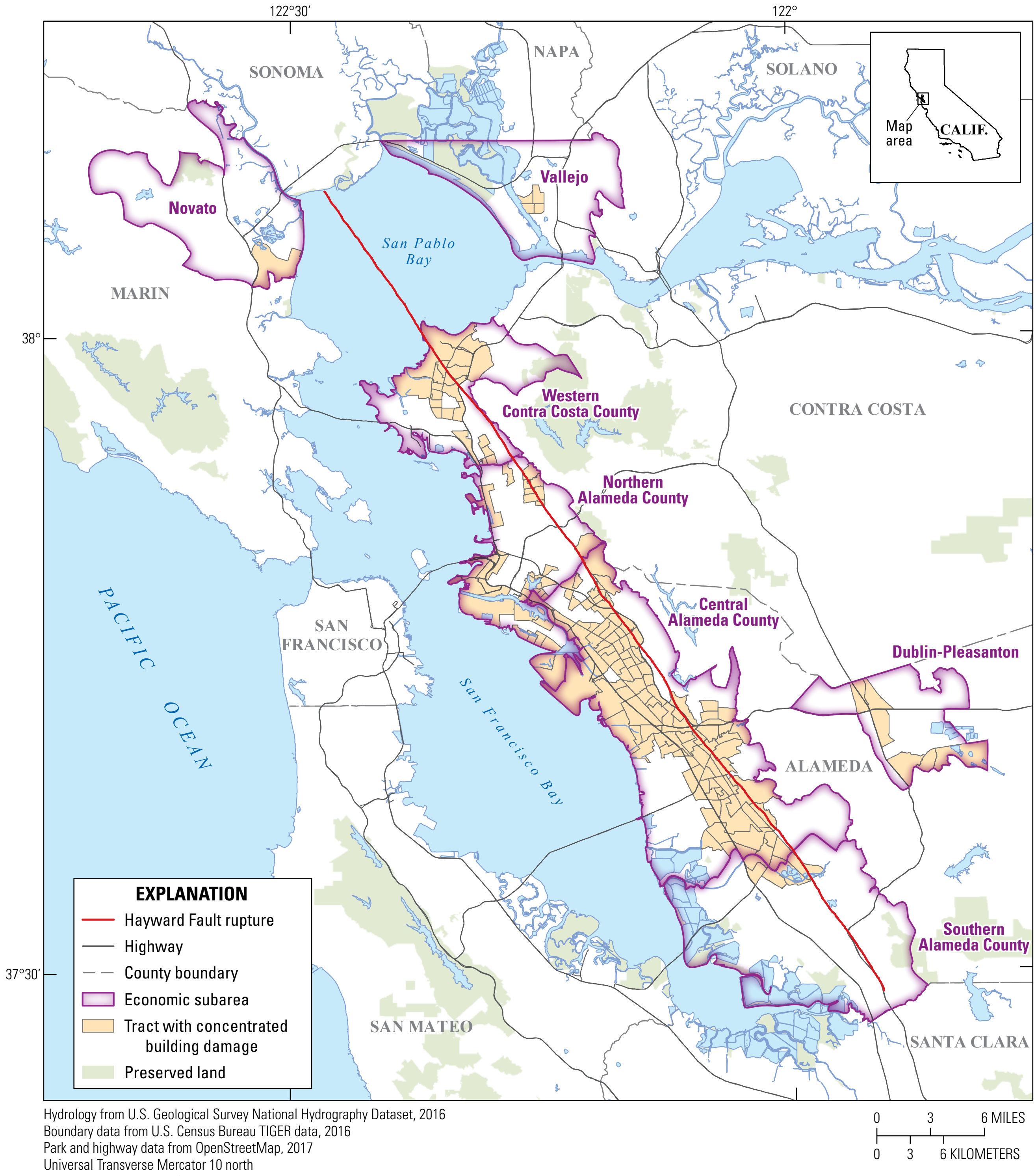


Figure 3. Map of the San Francisco Bay region, California, showing economic subareas and census tracts with concentrated damage in the HayWired scenario. Modified from Wein, Belzer, and others (this volume).

Therefore, in addition to the direct output loss estimated by USGS from building damages for less-affected areas, we need to account for how commute flow (table 9) and the transportation network affects businesses.

Less-affected areas in Alameda County employ about 452,000 workers, of which 72 percent commute from other parts of the bay region, including the heavily affected areas in Alameda, Contra Costa, Marin, and Solano Counties, as well as from counties outside the bay region. San Francisco, with a job base of about 695,000, is an example of a county with no heavily affected areas, but where 59 percent commute from areas outside San Francisco. For these types of less-affected areas, we added the loss from commute flow interruption to the loss from damaged buildings to get a total for output loss.

To translate commuting flow interruption from roadway and highway bridge damage into an output loss estimate (for less-affected areas) that is entered into the REMI model, we assumed that the percentage of output loss equals the percentage of all workers' working weeks lost in a year while commuters wait for repairs of roadways and bridges. We considered that commuters using these disrupted routes would seek alternative unblocked travel routes or modes (for example, ferry to avoid damaged bridges) if they think the new commuting time is still reasonable. Recall that in this scenario, bridges across San Francisco Bay are not estimated to sustain severe structural damages. Such outcomes would substantially disrupt commuters and increase business effects. We used Google Maps as our reference to select the optimal routes—routes that take the shortest time according to Google Maps—and to determine (somewhat subjectively) alternative commuting routes and the time it takes to use these routes. We then compared the new commute time with the shortest time suggested by Google Maps to decide whether commuters (as a group instead of individuals) would be willing to adopt the new routes given the marginal increase in commute time. We assumed those unable or unwilling to take alternative routes would have to wait for 7 months—midrange value of repair time for the most severely damaged roadways based on figure 2*A*—before they resume working. This would be time lost with regard to producing industry output.

We combined, for the less-affected areas in each county, the weeks lost by commuters waiting for roadways and bridges to reopen (table 10) and then divided the total lost commuter weeks by total commuter weeks (equal to the total number of commuters multiplied by 52) to get the share of lost commuter weeks. In order to calculate the share of total worker weeks lost for our model, we then multiplied the share of lost commuter weeks by the share of commuters calculated in table 9.

$$\textit{Commute share of output loss}$$
$$= \frac{\textit{Lost commuter weeks}}{\textit{Number of commuters} \times 52} \times \frac{\textit{Number of commuters}}{\textit{Number of workers}} \qquad (1)$$

For example, in San Francisco County (where the whole county is a less-affected area) for all sectors, 12 percent of the working weeks are lost because of transportation network damage. Therefore, we assume an additional 12 percent of total output loss for the county. In Alameda County, commuters are 72 percent of workers in less-affected areas, so the share of work weeks lost for this part of the county are 0.24 × 0.72 = 0.17 (or 17 percent; see the fourth column in the first row of table 10).

Based on the approach described above, table 10 shows that Alameda County is the most highly affected county, in regard to percentage of work time lost, with 17 percent of total workers' weeks lost. Although San Francisco and San

Table 9. Commuters in less-affected areas for the HayWired scenario in each county of the San Francisco Bay region, California.

[Data generated using an Association of Bay Area Governments analysis from 2018 (this study) of U.S. Census Bureau (2015) Longitudinal Employer-Household Dynamics (LEHD) data. LEHD job data is based on company payroll data, which might inflate the total number of commuters where company payroll data reporting location is different from actual workplace]

County	Total workers employed in less-affected areas	Total commuters to less-affected areas	Share of commuters, in percent
Alameda	451,877	323,221	72
Contra Costa	333,926	169,275	51
Marin	106,018	66,801	63
Napa	72,803	36,553	50
San Francisco	695,298	412,119	59
San Mateo	385,083	238,095	62
Santa Clara	1,001,412	385,077	38
Solano	139,565	76,004	54
Sonoma	191,411	56,271	29
Other Areas	1,802,175	785,233	44

Table 10. Percentage of weeks lost during the HayWired scenario because of transportation network interruption for all industry sectors for less-affected areas in each county of the San Francisco Bay region, California.

[Data generated using an Association of Bay Area Governments analysis from 2018 (this study) of U.S. Census Bureau (2015) Longitudinal Employer-Household Dynamics (LEHD) data and Jones and others (this volume). LEHD job data is based on company payroll data, which might inflate the total number of commuters where company payroll data reporting location is different from actual workplace]

County	Total commuter weeks	Total lost commuter weeks	Commuter weeks lost, in percent	Total worker weeks lost, in percent
Alameda	16,807,492	4,088,725	24	17
Contra Costa	8,802,300	1,638,960	19	9
Marin	3,473,652	339,518	10	6
Napa	1,900,756	93,944	5	2
San Francisco	21,430,188	4,245,934	20	12
San Mateo	12,380,940	2,105,963	17	11
Santa Clara	20,024,004	3,428,082	17	7
Solano	3,952,208	311,476	8	4
Sonoma	2,926,092	131,547	4	1
Other Areas	23,078,536	1,382,194	6	2

Mateo Counties experience less severe building damage than Alameda and Contra Costa Counties, commuters in these counties lose around 10 percent of their working time as the cross-boundary commute flow is interrupted.

There are some minor variations in vulnerability to commute flow interruption by industry type, as shown in table 11. We calculated the share of total worker weeks lost by three industry groupings, defined and discussed by Wein, Belzer and others (this volume), who separate out commute activity by industry grouping. In general, trade, transportation, and utilities jobs tend to have a slightly higher share of workers vulnerable to commute interruption than either goods-producing or services industries.

These percentages do not translate directly into output loss shares. Businesses and workers are very flexible and resilient in commuting and working. For example, telecommuting and working from home, an option 6 percent of workers in the region chose in 2016 (U.S. Census Bureau, 2016 [American Community Survey, 1 year]), could help keep businesses running, even more so for services industries rather than the goods producing, trade, transportation, and utilities industries. In addition, some commuters facing difficult or impossible commutes may choose to stay in hotels, with colleagues or friends, or in temporary living quarters near their offices during the week, particularly in places where buildings serving accommodation functions are not severely damaged. Taking into account these resiliency enablers, we applied factors to discount business output loss. In this analysis, we assumed one-third output loss from the effect of commuting in the goods producing, trade, transportation, and utilities industries, and one-fourth output loss in the services industry would occur. A method did not exist at the time of this study to objectively calculate how commute solutions would reduce the level of the commute disruption effect. However, fairly small shares were used in order to avoid exaggerating the effect.

For each REMI model subregion, we summed up the direct output loss from building damage of heavily affected areas and the combined output loss from building damage and transportation network interruption of less-affected areas to use as inputs to the REMI model. Among all 66

Table 11. Share of weeks lost because of transportation network interruption in the HayWired scenario by industry group for less-affected areas in each county of the San Francisco Bay region, California.

[Data generated using an Association of Bay Area Governments analysis from 2018 (this study) of U.S. Census (2015) longitudinal employer-household dynamics (LEHD) data; and Jones and other, this volume. LEHD job data is based on company payroll data, which might inflate the total number of commuters when company payroll data reporting location is different from actual workplace]

County	Goods producing	Trade, transportation, and utilities	Services
	Share of weeks lost, in percent		
Alameda	17	18	17
Contra Costa	8	12	9
Marin	6	8	6
Napa	2	3	2
San Francisco	12	13	12
San Mateo	12	12	10
Santa Clara	7	9	6
Solano	4	6	4
Sonoma	1	2	1
Other areas	2	3	1

private nonfarm industries, the professional, scientific, and technical services industry would experience the largest value of output loss in the San Francisco Bay region in the first year, approximately $4.4 billion, 3 percent of the industry's total output, followed by real estate ($4.3 billion, 3 percent), computer and electronic product manufacturing ($3.7 billion, 3 percent), food services and drinking places ($3.1 billion, 14 percent), and ambulatory health services ($2.6 billion, 9 percent). In the second year, total output loss is much smaller for the bay region (appendix 3). We again reduced the ABAG Regional Control Forecast output by this modified industry-specific loss in the REMI model.

Even with these conservative assumptions, the cumulative output loss effects from transportation network and commute flow interruption calculated in the model are as large as the output loss associated with building damage for the bay region. Employment loss increases from 232,000 to 498,000 jobs, and population decline expands from 50,000 to 105,000 people. As shown in table 12 and figure 4, loss of employment in the east bay subregion of the bay region rises from 159,000 to 228,000 jobs. The additional job losses in the west bay and south bay subregions are greater than the estimates from output losses from building damages alone in those areas. The west bay subregion loses 33,000 jobs because of building and contents damage, but an additional 108,000 jobs from commuting effects. Employment loss in the south bay subregion also increases by more than twofold.

In the San Francisco Bay region, the industry with the largest employment loss in the first year is food services and drinking places, with a loss of about 59,000 jobs (19 percent), followed by professional services (44,000 jobs, 7 percent) and retail trade (43,000 job, 10 percent). The construction sector loses 41,000 jobs (table 13). Total output loss approaches $106 billion in 2018 (2016 dollars) and increases by 120 percent from $48 billion if only output loss from direct building damage is considered. The real estate sector has the largest output loss ($11 billion), followed by professional services ($10 billion) and construction ($7 billion) (table 14 and appendix 4).

Table 12. Total employment and population effects in the HayWired scenario from building and transportation damage in 2018, San Francisco Bay region, California.

[Subregions are defined in table 3. Data generated using the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model; analysis of the HayWired scenario from 2018 (this study)]

Subregion	Employment loss	Employment loss as a percent of subregion jobs	Employment loss as a percent of total loss	Population loss[1]	Population loss,[1] in percent	Population loss[1,2] as a percent of total loss
East bay	228,106	14.54	46	55,436	2.0	53
North bay	20,467	3.53	4	6,996	0.7	7
West bay	141,229	8.22	28	23,680	1.2	23
South bay	107,776	7.64	22	18,555	0.9	18
San Francisco Bay region	497,578	9.8	100	104,668	1.3	100

[1]Population loss relates only to the population effects of the output and employment loss, not the losses because of outmigration as a result of residential building damage or loss of community services.

[2]Because of rounding, percentages may not be exact.

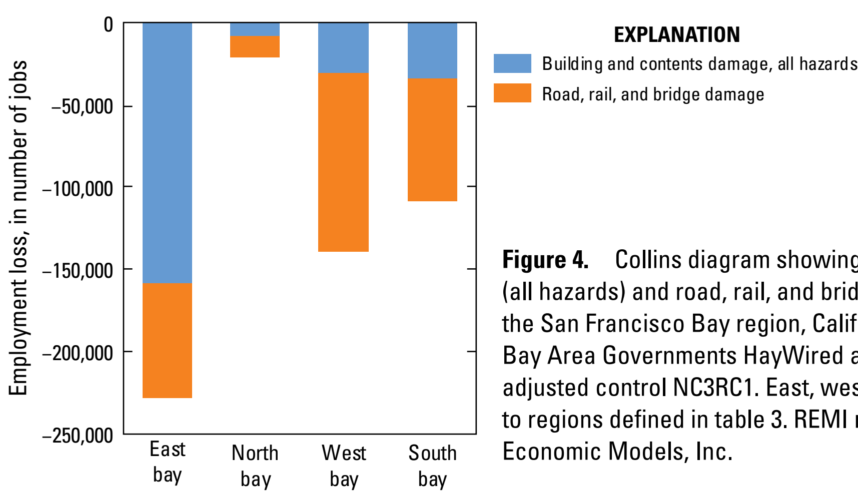


Figure 4. Collins diagram showing the HayWired scenario effects of building (all hazards) and road, rail, and bridge damage output loss on employment in the San Francisco Bay region, California. Data comes from the Association of Bay Area Governments HayWired analysis, using REMI model version 1.7.8, adjusted control NC3RC1. East, west, north, and south bay subregions refer to regions defined in table 3. REMI refers to models produced by Regional Economic Models, Inc.

Table 13. Ten industries with the largest employment loss from combined building and transportation effects in the San Francisco Bay region, California, in 2018.

[Data generated using the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model; analysis of the HayWired scenario from 2018 (this study)]

Sector category	Job loss	Job loss as a percent of sector jobs
Food services and drinking places	58,654	19.0
Professional, scientific, and technical services	44,174	6.6
Retail trade	43,011	10.2
Construction	41,434	16.2
Administrative and support services	31,846	10.3
Ambulatory health care services	25,735	14.3
Social assistance	20,220	9.2
Real estate	18,753	7.5
Wholesale trade	15,096	9.4
Performing arts and spectator sports	14,698	24.3

Table 14. Ten industries with the largest HayWired scenario total cumulative output loss from combined building and transportation effects in the San Francisco Bay region, California, in 2018.

[Data generated using the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model; analysis of the HayWired scenario from 2018 (this study)]

Sector category	Total output loss, in millions of dollars[1]	Output loss as a percent of sector output
Real estate	10,934.9	7.6
Professional, scientific, and technical services	9,531.9	6.5
Construction	6,772.3	16.5
Retail trade	4,993.2	10.3
Monetary authorities and other credit institutions	4,652.9	10.4
Ambulatory health care services	4,623.2	14.9
Wholesale trade	4,517.2	9.4
Food services and drinking places	4,174.5	18.7
Computer and electronic product manufacturing	4,091.2	3.2
Petroleum and coal products manufacturing	3,562.9	7.4

[1]2016 U.S. dollars.

Recovery Time Adjustment for Trade and Manufacturing Sectors

Empirical studies on business recovery for a range of crisis events, including hurricanes, earthquakes, and floods, have suggested that the more vulnerable businesses tend to be those that: are small; are reliant on discretionary income, such as retailers; are tenants rather than building owners; experience more severe damage; and (or) are closed for a longer period of time (Powell and Harding, 2007; Wein, Haveman, and others, this volume). In the HayWired scenario, manufacturing and mining companies are found to be more vulnerable because of direct output losses from building damages and effects of concentrated damages in their districts or neighborhoods (Wein, Belzer and others, this volume). Based on these findings we assumed an increase in the recovery time for retail trade, wholesale trade, mining, and selected manufacturing sectors. These manufacturing sectors consist of: wood product manufacturing; nonmetallic mineral product manufacturing; primary metal manufacturing; fabricated metal product manufacturing; machinery manufacturing; computer and electronic product manufacturing; electrical equipment and appliance manufacturing; motor vehicles, bodies and trailers, and parts manufacturing; other transportation equipment manufacturing; furniture and related product manufacturing; miscellaneous manufacturing; food manufacturing; beverage and tobacco product manufacturing; apparel manufacturing; leather and allied product manufacturing; paper manufacturing; petroleum and coal products manufacturing; chemical manufacturing; and plastics and rubber product manufacturing, which are based on data from Jon Haveman (Marin Economics Consultant, written commun., 2018). Specifically, we added 80 percent of the first-year direct output loss to the second-year direct output loss, 60 percent to the third year, and 40 percent to the fourth year for the retail sector in the east bay subregion. For nonretail sectors in the east bay subregion, we added 60 percent of the direct output loss estimated for 2018 to the second-year loss, 30 percent to the third year, and 10 percent to the fourth year. And for all sectors mentioned above in other subregions, we added 25 percent of the first-year direct output into the second-year loss and 5 percent to the third year. Assumptions of additional output loss for these sectors are shown in table 15. The differences reflect the degree of building damage in each of the REMI-defined subregions.

Table 15. Additional output loss as share of first year (2018) estimated output loss for the HayWired scenario in the San Francisco Bay region, California.

[Industry sectors of output loss considered are listed in parentheses. Subregions are defined in table 3]

Subregion	Output loss, in percent		
	2019	2020	2021
East bay (retail)	80	60	40
East bay (nonretail)	60	30	10
North bay (all)	25	5	0
West bay (all)	25	5	0
South bay (all)	25	5	0
Rest of California (all)	25	5	0

San Francisco Bay region employment loss reaches about 480,000 jobs in 2018 when building damage effects, transportation and commute flow effects, and the sector recovery time adjustments are combined; employment loss continues at a slower pace over the next four years of the scenario, and employment reaches a net gain of more than 4,600 jobs in 2022, five years after the earthquake. Ten years after the earthquake, the bay region still maintains a net gain of 6,000 jobs, but by 2040, the region is projected to have 1,300 fewer jobs than in the ABAG Plan Bay Area 2040 projection for the bay region, which is an insignificant difference from the projected 4.7 million jobs in 2040 (table 16).

Table 16. Total difference in employment numbers from revised output loss effects, relative to the Association of Bay Area Governments (ABAG) regional projection.

[Difference in employment numbers listed as negative where number of jobs are lost and positive where gained. Subregions are defined in table 3; Data generated using the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model; analysis of the HayWired scenario from 2018 (this study)]

Subregion	2018	2019	2020	2021	2022	2027	2040
East bay	−220,659	−42,429	−25,153	−10,515	526	2,861	−637
North bay	−19,953	−4,818	−2,714	−1,217	−314	275	−121
West bay	−136,545	−14,379	−5,565	−715	1,474	1,239	−347
South bay	−103,048	−16,626	−2,560	1,558	2,956	1,707	−191
San Francisco Bay region	−480,204	−78,252	−35,992	−10,888	4,642	6,084	−1,295
Percent compared to ABAG projection							
	−9.4	−1.5	−0.7	−0.2	0.1	0.1	0.0

Population in the bay region does not recover as fast as employment. The region loses about 101,000 people in the first year related to reductions in employment. By 2022, the population remains about 63,000 below projections (although 300,000 above the population level in 2018). Ten years after the earthquake, the region still has a net deficit of 25,000 people compared to the ABAG Plan Bay Area 2040 projection. By 2040, the region's population would slightly surpass the ABAG Plan Bay Area 2040 projection for the year, by around 1,000 people—again an insignificant difference in the projection of 9.5 million people in 2040 (table 17).

Effects on Population Beyond Employment

Up to this point in the discussion, the model analysis of the earthquake effects on population levels has come entirely through the changes to output—economic activity changes. Yet, as described by Johnson and others (Long-Term Recovery, in prep. [planned to be published as part of this volume]), the size of the labor supply and the characteristics of the labor force (such as education level, labor participation rate, age, and gender) of a region are some factors that determine the vitality of its economy. Post-disaster population movements and compositional changes that lead to regional labor force shifts would affect the economy. There is a broad base of household and community-scale socioeconomic characteristics that affect population displacement risk more than just race, income, and age (Esnard and others, 2011; Johnson and others, (Population Movements, in prep. [planned to be published as part of this volume]). After a disaster, businesses might relocate because of damages. They may choose more distant locations if the damage has left few available spaces. This can also disrupt their customer base, and population movement may even lead to the establishment of new economic centers outside the affected areas.

Johnson and others (Population Movements and Long-Term Recovery chapters, in prep. [planned to be published as part of this volume]) have extensively discussed areas at risk of population displacement and long-term community recovery challenges, such as assembling the resources for recovery; repairing and replacing damaged housing; finding interim housing; overcoming other recovery dependencies, such as jobs and neighborhood-serving businesses, transportation and utilities, and schools and community services; and addressing areas that require substantial replanning and intervention in order to recover. They estimate that about 216,000 to 268,000 households (almost 800,000 people and perhaps more) might be displaced in the short term in the HayWired scenario. However, long-term population movement remains hard to estimate, partly because of a lack of data and the complexity of different communities. In New Orleans, Louisiana, it took ten years for the city to regain 95 percent of its pre-Hurricane Katrina population, whereas in Puerto Rico, still recovering from Hurricane Maria, almost 90 percent of a sample of 407,000 people who left had returned home as of February 2018 (Echenique and Melgar, 2018).

The degree to which population displacement goes beyond the region is also complex to estimate. The region's total housing stock is large relative to the damage—households displaced from heavily damaged areas may find temporary or long-term living situations in other parts of the region. On the other hand, were the earthquake to happen during a period of very tight housing markets and rapidly escalating prices (as in 2017 and 2018), the costs could drive households who were barely able to afford their living situation prior to the disaster out of the region.

We used two levers in the model to address population displacement—housing prices and senior migration, which is a noneconomic migration in terms of how the model is structured.

Table 17. Total difference in population from revised output loss effects of the HayWired scenario, relative to the Association of Bay Area Governments Plan Bay Area 2040 projection for the San Francisco Bay region, California.

[Subregions are defined in table 3. Data generated using the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model; analysis of the HayWired scenario from 2018 (this study)]

Subregion	2018	2019	2020	2021	2022	2027	2040
East bay	−53,310	−48,627	−46,644	−42,134	−36,447	−16,077	134
North bay	−6,799	−6,791	−6,554	−5,900	−5,076	−1,782	55
West bay	−22,963	−19,388	−17,275	−14,741	−12,326	−4,196	467
South bay	−17,731	−15,100	−12,836	−10,692	−8,786	−3,131	291
San Francisco Bay region	−100,802	−89,906	−83,309	−73,467	−62,635	−25,186	947
Percent compared to ABAG projection							
	−1.3	−1.1	−1.1	−0.9	−0.8	−0.3	0.0

Post-earthquake Housing Price Changes

After nearly 170,000 properties were damaged in the Christchurch earthquake in New Zealand, the subsequent shortage in housing has resulted in a sharp increase in housing and rental prices. According to the Reserve Bank of New Zealand, housing prices in Christchurch are more than 40 percent higher than their pre-earthquake levels, which is more than double the increase that has occurred in the rest of New Zealand (Wood and others, 2016). Rents had increased by almost 50 percent in Christchurch by the start of 2015 (about four years after the initial earthquake in September 2010), compared with a nationwide increase of about 15 percent during that time. The increase in rents has been concentrated in the relatively unaffected suburbs because people have moved away from harder hit areas. This pattern is consistent with what has been observed after the 2017 Northern California wildfires. Housing prices in Sonoma County have increased faster than the whole San Francisco Bay region (North Bay Business Journal, 2018). Rents are also rising in the county and neighboring areas outside the immediate affected areas, although to a much lesser degree in Marin County; an observation perhaps attributable to Marin County's already high housing and rental prices (Halstead, 2018).

In the REMI model, we therefore increased the housing and rental prices for the four REMI subregions by the percentages shown in table 18 for the 7 years following the earthquake. We assumed that the price increase would remain relatively small in the first year, peak the fifth year, and then drop off as more housing and rental properties become available. We used "imputed rental of owner-occupied nonfarm" in the REMI model as the equivalent of housing sales price, and "rental of tenant-occupied nonfarm housing" for rents.

Post-earthquake Senior Outmigration Assumption

The housing price variable in combination with the economic variables captures some of the earthquake induced outmigration. Experience with the effects of the 2017 Northern California wildfires suggests that senior households may be particularly vulnerable to displacement, because of the costs and time involved in rebuilding. In this analysis, we chose to focus on retired migrants. Specifically, we assumed that seniors 65 years old and above that live with only a spouse, live in nonfamily households, or in group quarters in areas with concentrated damage would leave the region and not return. In 2016, there were 97,800 (5-year, American Community Survey, 2016) seniors in those heavily affected areas, more than 50 percent (50,400) of them meet the criteria for our assumption in this analysis. As such, we increased the outflow of retired migrants by 25,200 people in 2018, and by another 25,200 people in 2019 in the model.

We added these population effects into the REMI model with the effects on population from output changes described earlier. Job loss attributed to output losses from building damage, commute flow interruption, housing cost increases, and senior population displacement is estimated at around 515,000 jobs in 2018, around 96,000 five years after, and by 2040, the region still has a net loss of 10,000 jobs (table 19). Additionally, population loss for the region as a whole from the same effects, relative to projected levels, is estimated at around 150,000 people in 2018, around 264,000 people five years after, and by 2040, there remains a net loss of 23,000 people (table 20).

Table 18. Post-earthquake housing and rental price increases by year after the event, in percent, for the HayWired scenario in the San Francisco Bay region, California.

[Subregions are defined in table 3]

Detail	Subregion	1st	2d	3d	4th	5th	6th	7th
Imputed rental of owner-occupied nonfarm housing	East bay	5	5	10	15	30	5	5
Imputed rental of owner-occupied nonfarm housing	North bay	5	10	15	20	30	5	10
Imputed rental of owner-occupied nonfarm housing	West bay	5	5	10	10	10	5	5
Imputed rental of owner-occupied nonfarm housing	South bay	5	10	15	20	30	5	10
Rental of tenant-occupied nonfarm housing	East bay	5	5	15	20	30	5	5
Rental of tenant-occupied nonfarm housing	North bay	10	10	15	20	30	10	10
Rental of tenant-occupied nonfarm housing	West bay	5	5	10	15	20	5	5
Rental of tenant-occupied nonfarm housing	South bay	10	10	15	20	30	10	10

Table 19. Total employment difference from all loss effects in the HayWired scenario, relative to the Association of Bay Area Governments Regional Controls Forecast for the San Francisco Bay region, California.

[Difference in employment numbers is listed as negative where jobs are lost and positive where gained. Subregions are defined in table 3. Data generated using the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model; analysis of the HayWired scenario from 2018 (this study)]

Subregion	2018	2019	2020	2021	2022	2027	2040
East bay	−238,518	−74,107	−60,033	−49,803	−48,398	−736	−3,149
North bay	−22,844	−10,136	−10,194	−10,440	−12,164	−780	−1,224
West bay	−145,844	−25,566	−22,522	−21,334	−25,422	−1,058	−3,619
South bay	−107,998	−22,300	−10,550	−8,425	−9,622	1,635	−2,380
San Francisco Bay region[1]	−515,204	−132,108	−103,299	−90,002	−95,606	−940	−10,373
Percent compared to ABAG projection							
	−10.1	−2.6	−2.0	−1.8	−1.9	0.0	−0.2

[1]Because of rounding, sum totals may not be exact.

Table 20. Total population difference from all loss effects in the HayWired scenario, relative to the Association of Bay Area Governments Regional Controls Forecast for the San Francisco Bay region, California.

[Subregions are defined in table 3. Data generated using the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model; analysis of the HayWired scenario from 2018 (this study)]

Subregion	2018	2019	2020	2021	2022	2027	2040
East bay	−86,779	−114,681	−119,304	−124,574	−136,189	−77,351	−8,065
North bay	−9,555	−13,575	−18,353	−23,220	−29,483	−17,126	−2,743
West bay	−30,516	−32,132	−38,904	−46,389	−57,828	−30,583	−5,404
South bay	−23,114	−24,154	−27,760	−32,784	−40,533	−24,214	−66,56
San Francisco Bay region[1]	−149,965	−184,541	−204,321	−226,968	−264,033	−149,274	−22,867
Percent compared to ABAG projection							
	−1.9	−2.4	−2.6	−2.9	−3.3	−1.8	−0.2

[1]Because of rounding, sum totals may not be exact.

Assumptions and Simulated Effects within the REMI Model—Part 2: Rebuilding the Region

The elements described above consist of losses directly caused by building damage, transportation network interruption from the earthquake, and potential housing price increase, as well as senior outmigration, that reflect the displacement risks and recovery challenges in the region. In the following section we look at how Federal disaster relief funding and State and local government spending affects the level and pace of rebuilding.

Government Response and Recovery Investment

Following an earthquake of such scale (M_w 7.0), disaster declarations at the State and Federal level would be expected. For Federal fiscal years 2005 through 2014, FEMA obligated more than $104.5 billion from the Disaster Relief Fund for federally declared disasters across the country (U.S. Government Accountability Office, 2016), of which $25.4 billion was obligated for the Individual Assistance programs, $45.7 billion for Public Assistance programs, and $5.4 billion for the Hazard Mitigation Assistance program. The remaining $28 billion paid for FEMA administrative and mission assignment related costs. In addition to financial assistance available from the Disaster Relief Fund, during the same 10-year period, at least $173.1 billion across 17 Federal departments and agencies was provided for Federal disaster-specific and disaster-applicable programs and activities (U.S. Government Accountability Office, 2016), such as the Small Business Administration (SBA), which provides federally subsidized loans to repair or replace homes, personal property, or businesses that sustained damages not covered by insurance following a disaster, the Department of Housing and Urban Development Community Development Block Grant Program, the U.S. Department of Transportation Federal-Aid Highway Emergency Relief Program, the U.S. Department of Agriculture and Rural Assistance, and the U.S. Army Corps of Engineers Emergency Assistance.

There are three principal forms of Federal financial assistance from FEMA:

Public Assistance Program (FEMA, 2010).—This program provides grants to tribal, State, and local governments, and certain private nonprofit organizations to conduct debris removal operations (category A); provides emergency protective services (category B); and repairs or replaces damaged public infrastructure (category C-G). Although certain nonprofit organizations may be eligible for these grants, for-profit businesses are not.

Individual Assistance Program.—This program provides direct aid to affected households, can take the form of housing assistance (temporary housing, lodging expenses reimbursement, repair, replacement, and permanent or semipermanent housing construction), other needs assistance (child care, medical and dental expenses, funeral expenses, household, personal and work items, fuel, and moving expenses), crisis counseling, case management services, legal services, and disaster unemployment assistance. Total assistance under this program is capped at $33,300 per household, though that amount is adjusted annually (see https://www.fema.gov/individual-disaster-assistance for details on the program).

Hazard Mitigation Assistance Program.—This program funds mitigation and resiliency projects and programs typically across the entire State. This form of assistance is also cost shared. Mitigation projects can include the construction of safe rooms, buy-outs of frequently flooded properties, and retrofitting of facilities.

For Hurricane Katrina, Federal spending covered 72 percent of its damages, or $115 billion for the loss of $160 billion, whereas 80 percent of Hurricane Sandy's damages were covered by Federal spending. On average, the Federal Government has contributed funds to cover 62 percent of estimated damages for hurricanes that happened between Hurricanes Katrina and Sandy (Struyk, 2017). After the 2014 South Napa earthquake, financial assistance from FEMA and the California Governor's Office of Emergency Services reached $40.5 million, including $10.4 million in approved Housing Assistance Grants, $1.0 million in approved Other Needs Assistance Grants, and $5.5 million obligated Public Assistance Grants in categories A–B and $22.5 million in categories C–G (U.S. Department of Homeland Security and Federal Emergency Management Agency, 2014a). An additional $30.7 million in home disaster loans was given to 971 applicants and $10.7 million of business disaster loans to 125 applicants who were approved by the SBA (Carol Chastang, Public Affairs Specialist, U.S. SBA, written commun., 2018). SBA loans were included in the background analysis because they are an essential part of the recovery process that would increase spending in the economy. However, the potential effect of loan repayments was not included as part of the analysis. For the October 2017 Northern California wildfires, $18.0 million was approved under the Individual Assistance Program, and $357.9 million was approved under the Public Assistance Program (U.S. Department of Homeland Security and Federal Emergency Management Agency, 2014b). The SBA provided $151 million total in home and business disaster loans (Carol Chastang, Public Affairs Specialist, U.S. SBA, written commun., 2018). These recent figures were used to estimate the distribution of Government financial assistance, as discussed below.

Financial assistance from the Federal and State Governments is vital for the recovery and rebuilding of the region in the HayWired scenario because only 10 percent of residential fire insurance policyholders have earthquake insurance, and assistance from nonprofit organizations and foundations will be limited. CoreLogic, a real estate data company, estimates that insurance will only be able to cover 17.6 percent of the estimated losses—Federal assistance is important to bridge the funding gaps for the region's recovery (CoreLogic, 2018). Our model uses the assumption that insurance will only cover 15 percent of the estimated losses. Taking into account the timeline for releasing and spending approved grants and the cost-share factor between Federal, State, and local governments regarding governments' response, we assumed:

- Insured loss is 15 percent of the total estimated building-damage-related loss of $85 billion (2016 value). This consists of building, content loss, inventory, relocation cost, income, rent, and wage losses only for the nine San Francisco Bay region counties as estimated by Seligson and others (2018);
- Government assistance from all levels covers two-thirds of the uninsured loss; one-third of the uninsured loss is not recovered;
- Two-thirds of government assistance is spent on rebuilding, the other one-third covers all administrative functions;

- State and local governments are responsible for one-fourth of all government assistance, the rest is exogenous Federal spending into the region;
- Spending would be used throughout a 9-year period distributed by 10, 10, 20, 20, 15, 10, 5, 5, and 5 percent from the first to the ninth year; and
- Distribution of grants by San Francisco Bay subregion is based on the distribution of building damage related losses by subregion.

At the same time, spending from government, businesses, and individuals with the money received as part of the recovery could be seen as reinvestment into the region's economy: rebuilding and restoration of housing units, commercial properties, and public facilities will create huge demand in the construction sector, consumer spending on apparel and household items, and educational and healthcare services will also spur the recovery and growth of the economy. During 2011, when three magnitude 6 aftershocks affected Christchurch, New Zealand in February, June, and December, employment in the region kept falling through mid-2012 and has since risen by about 16 percent as of early 2016. The ratio of construction employment in Canterbury, New Zealand, to nationwide construction jobs has doubled, whereas corresponding ratios in other industries have fallen or remained flat (Wood and others, 2016). Retail sales in Christchurch held up well relative to nationwide sales in the initial period after the earthquakes, but experienced a noticeable increase since 2012, which slowed down in mid-2015. At the same time, import volumes into Canterbury have increased by more than nationwide imports as rebuild-related materials and replacement goods have been brought in (Wood and others, 2016). Given the observed delay in construction starts and retail sales increases, in this analysis, we assume:

- Three-fourths of government nonadministrative spending would be spent in the construction sector, and the remaining quarter would be spent on 28 selected consumer commodities (appendix 6);
- Spending in construction would be spread across a 9-year period, as recommended by volume coauthor Laurie Johnson (Laurie Johnson Consulting, written commun., 2018), based on her experience with the pace of recovery in other U.S. natural disasters, distributed by 10, 10, 20, 20, 15, 10, 5, 5, and 5 percent from the first to ninth year;
- Spending in consumer products would be used throughout a 10-year period distributed by 2.5, 7.5, 10, 20, 20, 15, 10, 7.5, 5, and 2.5 percent from the first to tenth year;
- Distribution of grants by San Francisco Bay subregion is based on the distribution of building damage related losses (the sum of building, contents, and inventory repair and replacement costs, relocation costs, income losses, and output losses) by subregion.

Government spending and recovery have a stimulating effect on the economy that can counteract some of the job and population losses. To understand the effect of government spending alone on employment and population, we first increased government spending in the ABAG Regional Control Forecast without including the effects of output loss or population outmigration loss. When added to the ABAG Regional Control Forecast, government spending creates 19,000 jobs in 2018, which increases to more than 39,000 in 2020 as the speed of recovery picks up. The effects disappear after the grants are exhausted. Meanwhile, the economic activity stimulated from this spending brings an additional 5,000 people to the San Francisco Bay region in 2018, and as many as 27,000 by 2022. By 2040, and assuming no further damaging earthquakes, the cumulative effects of recovery spending are no longer apparent compared to expected levels from the ABAG Regional Control Forecast. However, recovery would have been delayed without the recovery spending (tables 21, 22).

Table 21. Total employment gain from recovery spending, relative to the Association of Bay Area Governments Plan Bay Area 2040 projection for the San Francisco Bay region, California.

[Subregions are defined in table 3. Data generated using the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model; analysis of the HayWired scenario from 2018 (this study)]

Subregion	2018	2019	2020	2021	2022	2027	2040
East bay	10,857	12,183	22,142	24,313	19,582	−91	443
North bay	637	804	1,556	1,822	1,529	78	58
West bay	3,418	3,844	6,933	7,594	5,894	−308	114
South bay	4,177	4,539	8,305	8,743	6,650	−847	72
San Francisco Bay region[1]	19,089	21,370	38,936	42,472	33,654	−1,169	686

[1]Because of rounding, sum totals may not be exact.

Table 22. Total population gain from recovery spending in the HayWired scenario, relative to the Association of Bay Area Governments regional projection for the San Francisco Bay region, California.

[Subreginos are defined in table 3. Data generated using the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model; analysis of the HayWired scenario from 2018 (this study)]

Subregion	2018	2019	2020	2021	2022	2027	2040
East bay	3,190	5,931	11,275	16,099	18,838	14,645	1,484
North bay	239	481	948	1,410	1,693	1,314	86
West bay	520	969	1,794	2,522	2,848	1,710	31
South bay	651	1177	2,199	3,062	3,462	2,115	91
San Francisco Bay region[1]	4,600	8,558	16,216	23,093	26,841	19,784	1,691

[1]Because of rounding, sum totals may not be exact.

HayWired Scenario Combined Effects on Employment and Population

Running the REMI model with all of the assumptions included shows a regional economy that could experience a deep recession (or depression in the east bay subregion of the San Francisco Bay region). It would ultimately recover, but some parts of the region do not recover to pre-earthquake employment levels until about 2025 (fig. 5*A*). Compared to projected employment and population levels, the region returns to within about 1 percent of the projected employment track by 2025 (fig. 5*B*). The absolute population in the region recovers more quickly than the employment totals (fig. 6*A*), but compared to the regional projection without an earthquake, the population level is reduced for more than a decade, especially in the east and north bay subregions (fig. 6*B*).

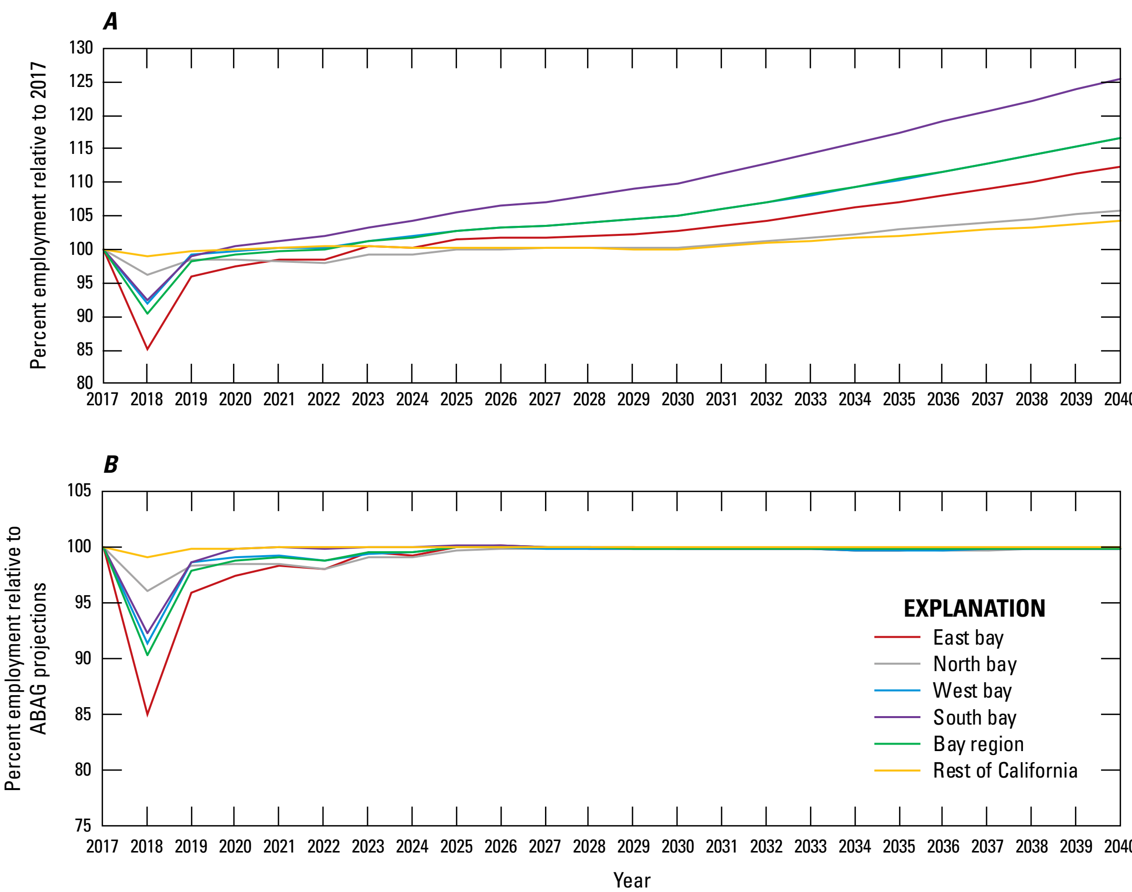


Figure 5. Graphs of employment curves in the HayWired scenario for the San Francisco Bay region, California, relative to 2017 levels (*A*) and the Association of Bay Area Governments (ABAG) Plan Bay Area 2040 projection (*B*). Data generated using the ABAG Planning and Research Department (2016) REMI model; analysis of the HayWired scenario from 2018 (this study). East, west, north, and south bay are defined in table 3. Bay region refers to the San Francisco Bay region. REMI refers to models produced by Regional Economic Models, Inc.

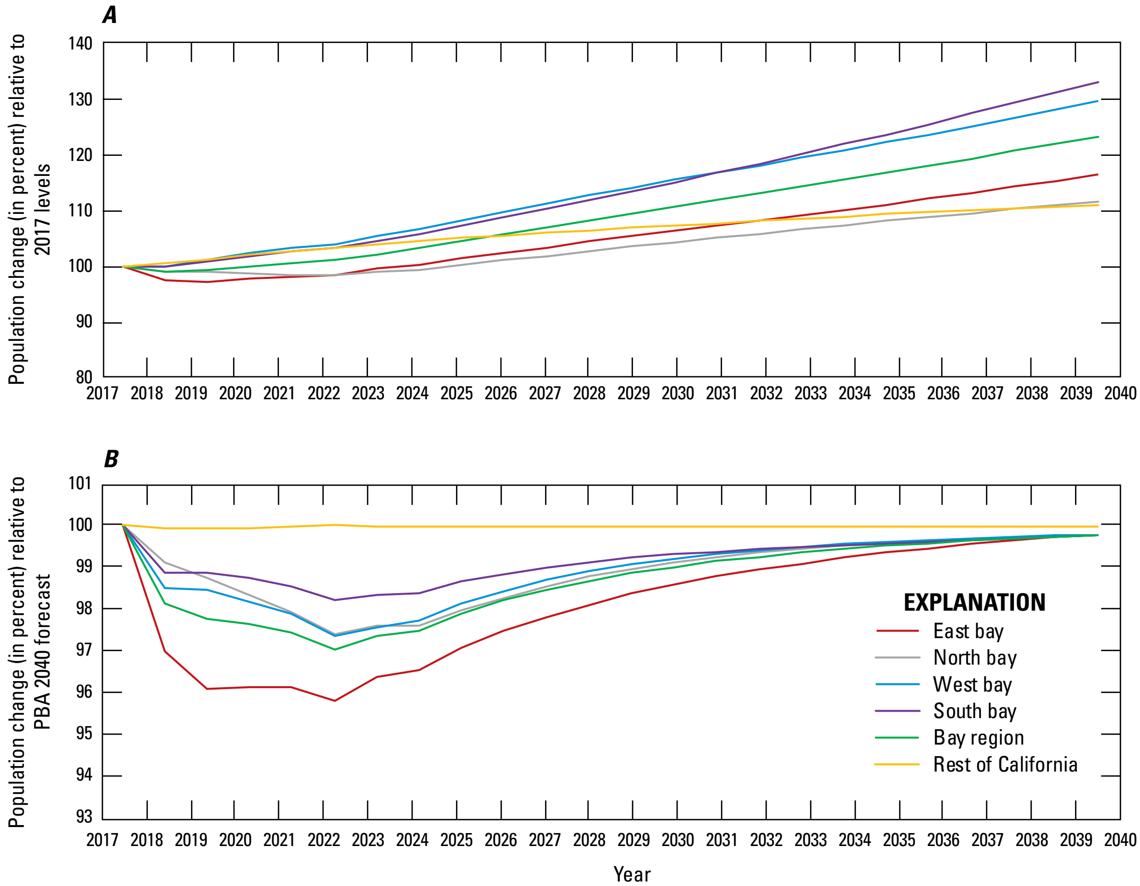


Figure 6. Graphs of population curves in the HayWired scenario for the San Francisco Bay region, California, relative to 2017 levels (*A*) and the Association of Bay Area Governments (ABAG) Plan Bay Area 2040 (PBA2040) projection (*B*). Data generated using the ABAG Planning and Research Department (2016) REMI model; analysis of the HayWired scenario from 2018 (this study). East, west, north, and south bay are defined in table 3. Bay region refers to the San Francisco Bay region. REMI refers to models produced by Regional Economic Models, Inc.

Employment Effects

All assumptions included, the region's net employment loss in the first year is more than 496,000 jobs, a 10 percent decrease compared to the regional control forecast (fig. 5*B*). All sectors experience job losses in the first few years after the earthquake. Food service and drinking places has the largest employment loss in 2018, almost 59,000 jobs (19 percent), followed by professional services (44,000 jobs or 7 percent), retail trade (43,000 jobs or 10 percent), and administrative services sector (32,000 jobs or 10 percent). By 2040, the region has a net job loss of 10,000, which can be attributed to losses in all sectors except petroleum manufacturing and apparel manufacturing (fig. 7). Appendix 5 shows detailed industry net employment change.

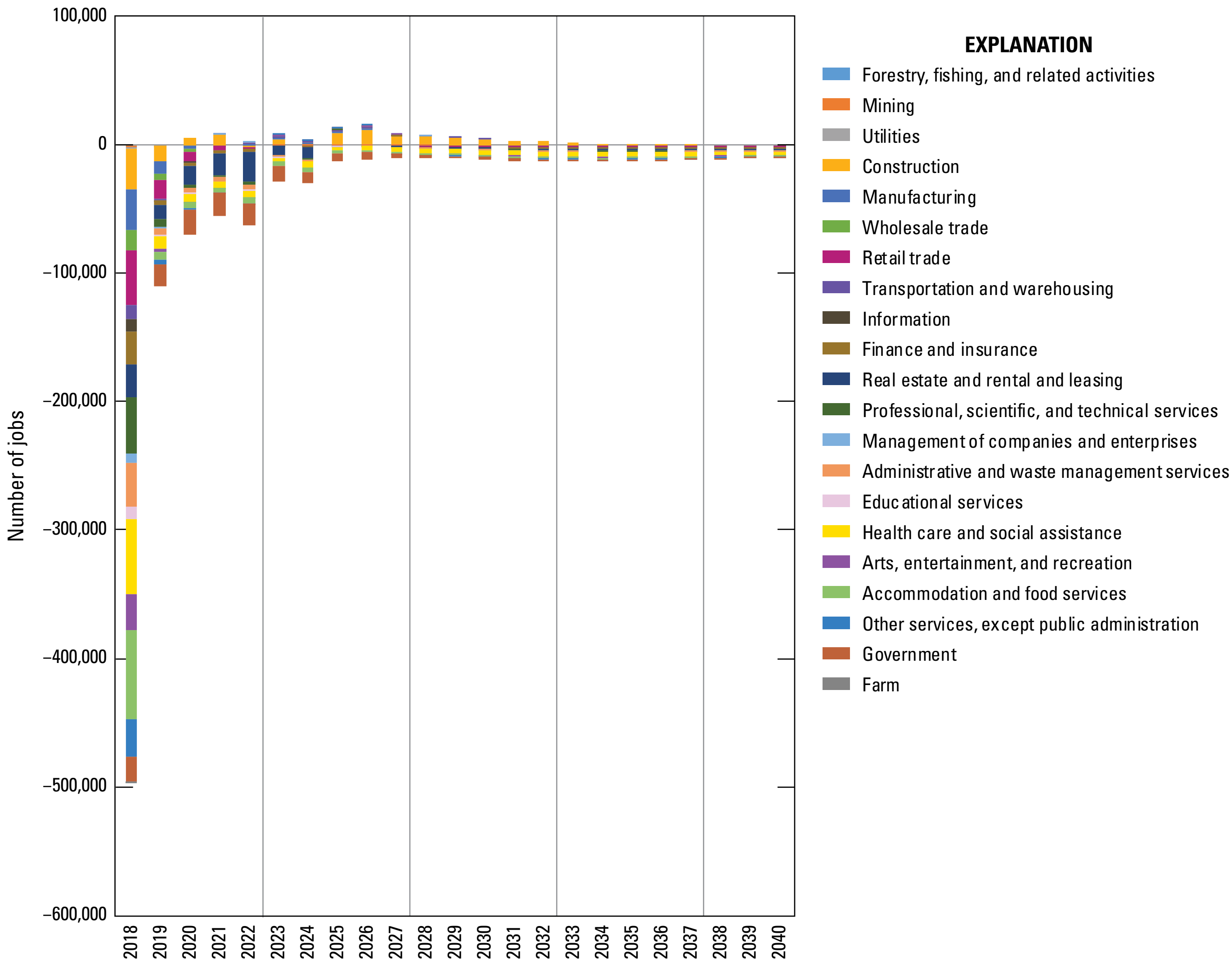


Figure 7. Collins diagram showing San Francisco Bay region, California, net employment change by sector in 2018–2040 for the HayWired scenario. Data from the Association of Bay Area Governments Planning and Research Department (2016) REMI model version 1.7.8, adjusted control NC3RC1. REMI refers to models produced by Regional Economic Models, Inc.

Population Effects

Combining the loss and stimulus effects, the San Francisco Bay region population decreases by about 145,000 in 2018, of which a decrease of 83,000 people occurs in the east bay subregion. Population net loss, especially from senior outmigration after the earthquake in the east bay subregion, continues to drive the earthquake's negative effects on the region's population until 2040. Housing price increases in other subregions also drive residents outside of the bay region. By 2040, the bay region population remains at a net loss of about 21,000 people compared to the ABAG Regional Control Forecast (fig. 8).

Gross Regional Production Effects

Overall, San Francisco Bay region GRP decreases by about $67 billion in 2018, almost 10 percent of GRP, of which a $26 billion loss occurs in the east bay subregion, $22 billion in the west bay subregion, and another $16 billion in the south bay subregion. The north bay subregion loss is the smallest, approximately $2 billion. Loss in GRP changes as recovery activities enter different stages. By 2040, the bay region GRP remains a net loss of about $1 billion relative to GRP projections from the Plan Bay Area 2040 regional projection, or less than one-tenth of one percent of the plan's projected GRP (fig. 9).

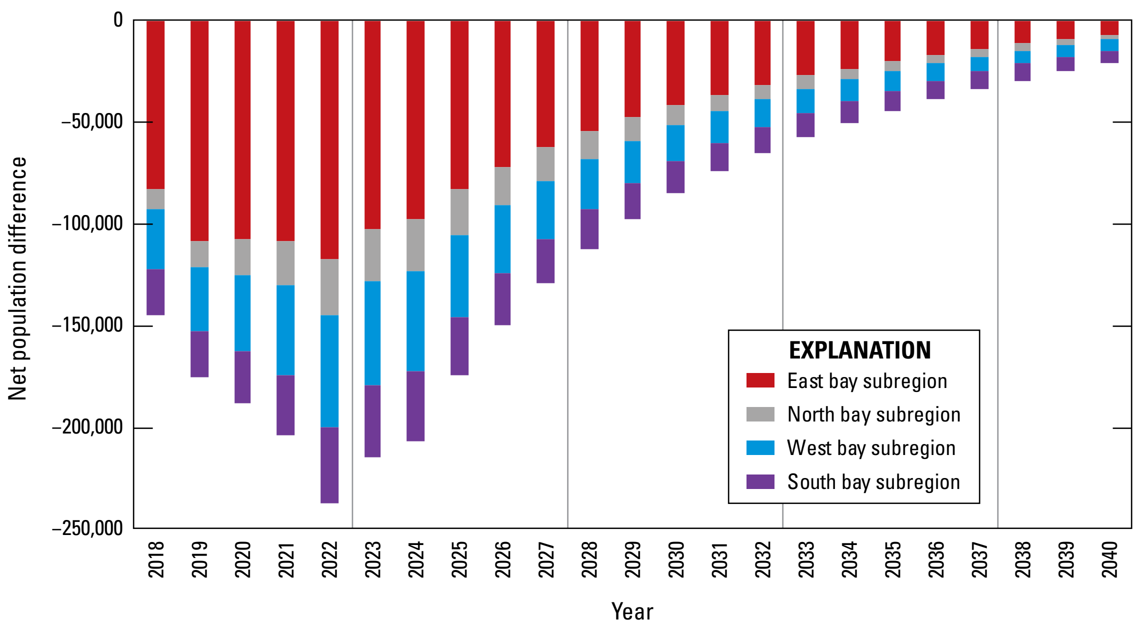


Figure 8. Collins diagram showing San Francisco Bay region, California, net population difference by subregion for the HayWired scenario compared to the Association of Bay Area Governments (ABAG) Regional Control Forecast. Data from ABAG Planning and Research Department (2016) REMI model version 1.7.8, adjusted control NC3RC1. Subregions are defined in table 3. REMI refers to models produced by Regional Economic Models, Inc.

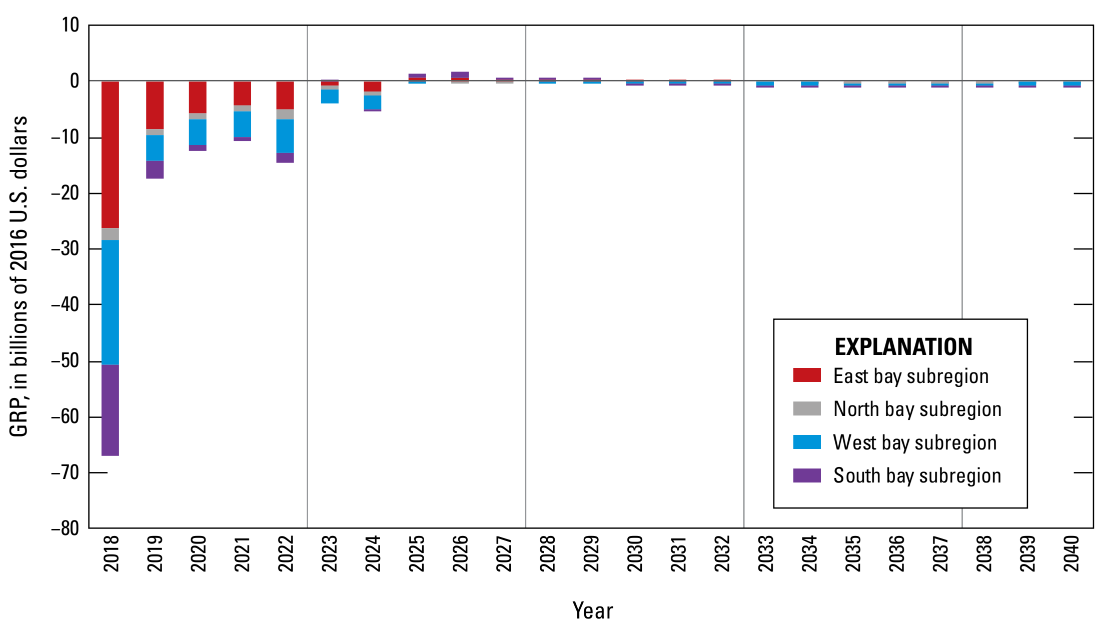


Figure 9. Collins diagram of San Francisco Bay region, California, net gross regional product (GRP) change by subregion for the HayWired scenario compared to the Association of Bay Area Governments (ABAG) Regional Control Forecast. Data from ABAG Planning and Research Department (2016) REMI model version 1.7.8, adjusted control NC3RC1. Subregions are defined in table 3. REMI refers to models produced by Regional Economic Models, Inc.

Summary of REMI Simulation of HayWired Scenario Effects

This analysis shows an economy that would experience substantial damages and losses in the short term from a magnitude 7.0 earthquake on the Hayward Fault. Much of the economy could recover within a few years, although a full return to the previous trajectory could take more than five years for the region and closer to a decade for the most severely affected counties. Recovery and rebuilding investments will be crucial to repairing the economic base of the region and returning to its projected growth trajectory.

The most severe economic losses are concentrated in the east bay subregion, where in 2018, there are reductions in GRP by 13 percent, employment by 15 percent, and population by 3 percent (table 23). Other parts of the region,

Table 23. Summary of year 1, year 5, year 10, and 2040 employment, population, and gross regional product (GRP) levels in the HayWired scenario relative to Plan Bay Area 2040 projections for the San Francisco Bay region, California.

[Subregions are defined in table 3. Negative percentage change in parentheses. GRP change is in billions of 2016 U.S. dollars. Data from the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model version 1.7.8, adjusted control NC3RC1]

Subregion	2018	2022	2027	2040
		Employment		
East bay	−227,564	−28,837	−915	−2,678
	(0.15)	(0.02)	(0.00)	(0.00)
North bay	−22,213	−10,661	−706	−1,164
	(0.04)	(0.02)	(0.00)	(0.00)
West bay	−142,438	−19,530	−1,389	−3,492
	(0.09)	(0.01)	(0.00)	(0.00)
South bay	−103,827	−2,959	772	−2,300
	(0.08)	(0.00)	0.00	(0.00)
San Francisco Bay region	−496,042	−61,987	−2,238	−9,634
	(0.10)	(0.01)	(0.00)	(0.00)
		Population		
East bay	−82,978	−117,468	−62,738	−6,738
	(0.03)	(0.04)	(0.02)	(0.00)
North bay	−9,313	−27,874	−15,846	−2,648
	(0.01)	(0.03)	(0.02)	(0.00)
West bay	−30,011	−55,005	−28,886	−5,349
	(0.02)	(0.03)	(0.01)	(0.00)
South bay	−22,408	−37,122	−22,120	−6,559
	(0.01)	(0.02)	(0.01)	(0.00)
San Francisco Bay regiona	−144,710	−237,469	−29,590	−21,294
	(0.02)	(0.03)	(0.02)	(0.00)
		GRP change		
East bay	−26.07	−5.15	0.40	−0.07
	(0.13)	(0.02)	0.00	(0.00)
North bay	−2.31	−1.44	−0.02	−0.11
	(0.03)	(0.02)	(0.00)	(0.00)
West bay	−22.29	−6.34	0.00	−0.42
	(0.08)	(0.02)	0.00	(0.00)
South bay	−16.21	−1.54	0.42	−0.26
	(0.06)	(0.01)	0.00	(0.00)
San Francisco Bay region	−66.88	−14.47	0.80	−0.86
	(0.08)	(0.02)	0.00	(0.00)

as well as neighboring counties, also experience losses and disruptions to work caused by building damage. These losses are exaggerated by disruptions to the transportation system. In 2018, the west bay subregion loses 8 percent in GRP, 9 percent in employment, and 2 percent in population; the south bay subregion loses 6 percent in GRP, 8 percent in employment, and 1 percent in population; and the north bay subregion loses 3 percent in GRP, 4 percent in employment, and 1 percent in population. The rest of California is estimated to lose more jobs than the west and south bay subregions (171,000 in places outside the bay region) and more people than the south bay subregion (23,000) in 2018. Although bay region employment, population, and GRP fall below the ABAG Regional Control Forecast for Plan Bay Area 2040, the negative effects are insignificant by 2040.

The HayWired analysis shows employment losses experienced in the east bay subregion will be much sharper and deeper than during recent recessions but will have a faster rate of recovery than from either the "dot-com" (2001–2004) or financial crisis (2008–2010) related recessions (fig. 10A). For the San Francisco Bay region as a whole (fig. 10B), employment losses are of a magnitude similar to that experienced in the "dot-com" bust, but it ultimately took the region much longer to recover the jobs lost then than the recovery illustrated here.

Achieving this pace of recovery happens naturally in the model but in actuality is not guaranteed, nor is it independent of policy actions taken before or after an earthquake. The following sections discuss limitations to the analysis, how different assumptions could affect the model results, and finally how policies before and after the earthquake may also determine the outcomes for individuals, communities, and the region as a whole.

Caveats and Limitations

In a number of ways, this economic analysis incorporates significant resilience features. The REMI model has built-in resilience, with a tendency to return to long-term trends over time. Our application of assumptions also includes some resilient features, with the expectation that transportation disruptions are moderated by worker behavior (finding alternative travel routes), employer adjustments (encouraging telecommuting), and a range of supports for housing workers close to jobs.

The assumptions provided by major transportation and utility providers also suggest expectations of a sequence of repairs that would allow the economy to return to normal within a year. Water, utilities, and communications are expected to be mostly restored within a few weeks to a couple of months. Where repairs are expected to take longer (for example, the BART line running south of Oakland to Fremont on fig. 2*B*), alternative transportation modes (buses, ferries, carpools, and individual drivers) can provide alternative travel options, once bridges are repaired. Some water repairs in limited parts of Alameda and Contra Costa Counties could take as long as six months, but this is incorporated in the population relocation and business dislocation assumptions.

If the restoration of services proceeds as assessed by the providers, then most of the negative effects occur in

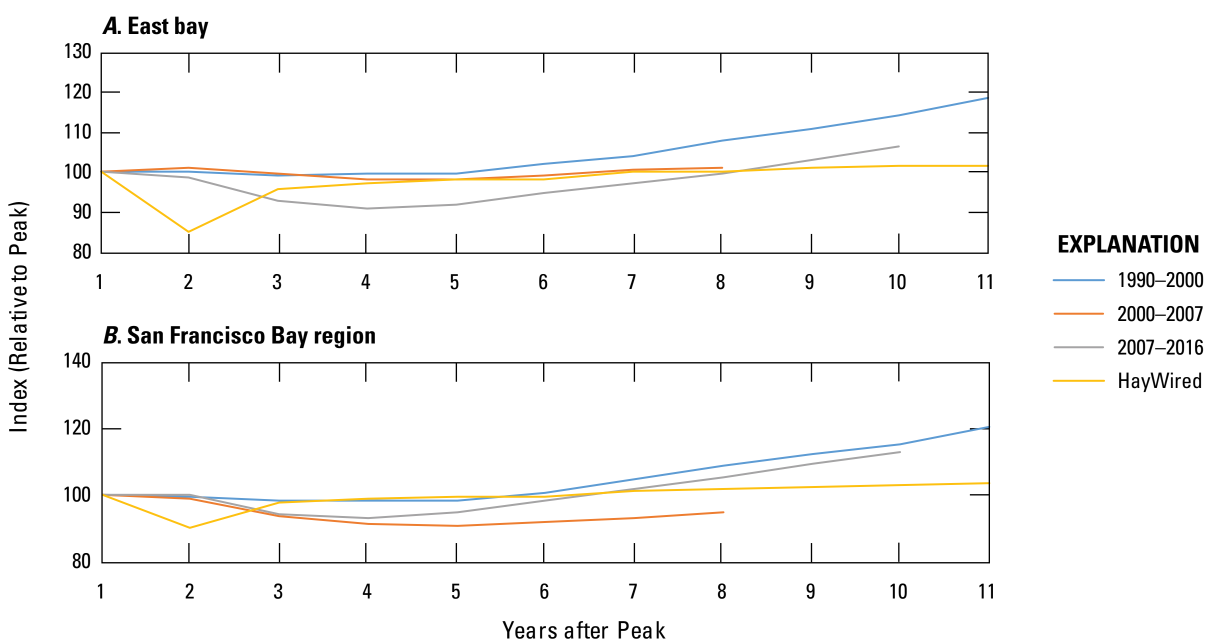


Figure 10. Graphs showing the recovery progression from prerecession peak to peak of recovery or next upturn for the east bay subregion (*A*) and San Francisco Bay region, California (*B*), compared to job projection in the HayWired scenario. Data from California Employment Development Department (2018) and Association of Bay Area Governments Planning and Research Department (2016) REMI model version 1.7.8, adjusted control NC3RC1. REMI refers to models produced by Regional Economic Models, Inc.

the first year. The job loss returns to below one percent of forecasted employment and population levels in the second year, assuming continued access to labor and goods from outside of the region and assuming substitution between labor and capital (that is, the built-in resilience of the economy in the model). Government recovery assistance is a key factor in this assessment, which significantly reduces the negative consequences of the earthquake through time and expedites the recovery process. In reality (as opposed to the model), the effectiveness of this recovery assistance will depend not only on the amount of dollars provided but on the capacity of State and local government to effectively allocate the resources and to efficiently manage the recovery efforts.

A number of factors and assumptions could change the outcome of this analysis. On the positive side, the Hazus-based estimate of building damage in 2018 could be high when applied as a percentage, especially for multifamily and office buildings. To the extent that the overall stock has a higher share of newly constructed buildings than the base used for the Hazus assessment, the share of buildings and square footage that experience extreme or complete damage may be lower than assumed for this analysis. Effective retrofit programs on residential units could reduce the number of displaced residents and decrease rebuilding costs after the event. These are not included in the model because of the timing of the event. Were this type of event to happen instead five years hence and were effective retrofits in place in a substantial number of buildings, the negative effects would be reduced.

Inclusion of insurance payments as a portion of rebuilding investment could reduce the amount of government spending cutbacks required, softening the adjustments made to the overall effects of government spending. We did not explicitly separate out insurance payments in the assessment because they would not be large relative to the damage. The built-in resilience in the model could be interpreted as including natural reinvestment that occurs in an area following a downturn, which could include the outside insurance payments. In contrast, government payments are an additional outside stimulus that would not be available to the region's economy without the earthquake and explicit recovery policy by Federal, State, and local agencies.

Our application of the REMI model does not model the unanticipated future evolution of industry in the San Francisco Bay region. For example, just as the "birth" of Silicon Valley provided a huge economic stimulus to the region, unforeseen new industries that could develop before 2040 would affect the amount of investment, the characteristics of industries, and, therefore, the speed of economic recovery, in the region. The model and analysis also do not explicitly include possible new industries that could emerge from the earthquake—for example, technology fixes to apply to seismically risky areas or industries that flourish as low-cost space emerges in heavily affected areas. The built-in resiliency feature of the model essentially relies on the ability of the region to respond in this way but, it does not assume the region recovers in a stronger growth path than would occur otherwise. Similarly, the model does not explicitly address changes in occupational training and labor productivity that would come from a significant structural change in the recovering economy. The San Francisco Bay region has a large enough economy that even with the devastating effects to the east bay subregion, the majority of the basic industries that are the major drivers of the economy would likely continue to operate, albeit at a reduced or adjusted level for location in the short run.

There are other factors that could lead to long-term changes in the outcome of the scenario. We have tried to account for a number of these effects with the model, but the levels of effect used could be too optimistic:

- Rising home prices and rents may move unevenly. Sales may be curtailed in the worst hit parts of the region, and land prices may drop, leading to foreclosures on loans, homelessness, or departure from the region for additional households.
- Higher wages paid to construction workers and worker shortages may delay rebuilding and repairs.
- Population displacement effects could persist for longer, especially in heavily affected parts of the east bay subregion. The slower repair of water systems in some of the heavily affected areas, not explicitly included, could increase the population displacement effects. The negative effect on population could be further exaggerated if inmigration is dampened for several years in the future, extending other effects as well for a longer period of time.
- We may have been too optimistic in our assessment of the ability of commuters to make flexible work arrangements or their willingness to adapt to alternate (and more time-consuming) routes.
- Branch operations may be closed down permanently as large employers reroute operations to other locations in the United States or globally.
- The need for planning for heavily affected areas may delay rebuilding even beyond the delays incorporated into the model.
- The earthquake could have a significant effect on local revenues and spending, beyond the shift in spending towards reconstruction activities. Places damaged by natural disasters are generally

reassessed, lowering the property tax revenues to local jurisdictions. This could cause sharp budgetary cuts, with consequent employment and income implications for some smaller east bay cities, where real-estate-related taxes and fees can account for close to half of all revenues, as estimated by the authors using California State Controller 2016 city budget data (California State Controller's Office, 2018). A back-of-the-envelope analysis shows that the share of lost revenues linked directly to building damage could be as high as 10 percent in smaller cities near the epicenter, and these shares could be substantially higher if inaccessible areas (owing to concentrated neighborhood damage and cordons) are considered.

Sensitivity Tests

Sensitivity tests were run on how changes in a few post-event factors could affect the results.

Construction Costs

If construction costs are increased for a 5-year period relative to their assumed levels in the model (by 20 percent in the first year, 40 percent in the second, 60 percent in the third and fourth years, and 40 percent in the fifth year) to reflect the unusually high demand for workers and construction materials, then the result is an additional 124,000 jobs lost in 2018, which expands to a loss of more than 401,000 more jobs in 2020 and 2021 when construction demand is particularly high because of recovery spending. By 2040, the San Francisco Bay region would lose an additional 22,000 jobs. The east bay and west bay subregions would lose an additional 174,000 and 129,000 jobs, respectively, in 2021. Bay region employment would not recover to the pre-earthquake level until after 2024. Population loss would increase by 47,000 people in 2018, and population levels would be lower by 348,000 in 2022. By 2040, the bay region population would be an additional 50,000 people fewer than in the primary HayWired scenario analysis described above. Table 24 shows the effects on the east bay subregion employment, population, and GRP; table 25 summarizes effects for the entire bay region.

Table 24. Employment, population, and gross regional product (GRP) effects with higher construction costs in the HayWired scenario relative to Plan Bay Area 2040 projections for the east bay subregion of the San Francisco Bay region, California.

[Negative percentage change in parentheses. East bay subregion refers to Alameda and Contra Costa Counties. Data from the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model version 1.7.8, adjusted control NC3RC1]

Affected categories	2018	2022	2027	2040
Employment	−274,559	−184,745	−14,652	−8,699
	(0.18)	(0.12)	(0.01)	(0.01)
Population	−104,263	−268,555	−165,078	−23,611
	(0.04)	(0.10)	(0.06)	(0.01)
GRP, in billions of 2016 U.S. dollars	−32.13	−27.37	−2.38	−1.19
	(0.16)	(0.13)	(0.01)	(0.01)

Table 25. Employment, population, and gross regional product (GRP) effects with higher construction costs in the HayWired scenario relative to Association of Bay Area Governments Plan Bay Area 2040 projections for the San Francisco Bay region, California.

[Negative percentage change in parentheses. Data from the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model version 1.7.8, adjusted control NC3RC1]

Affected categories	2018	2022	2027	2040
Employment	−619,322	−474,817	−49,427	−31,567
	(0.12)	(0.09)	(0.01)	(0.01)
Population	−192,190	−587,373	−367,948	−70,814
	(0.03)	(0.07)	(0.04)	(0.01)
GRP, in billions of 2016 U.S. dollars	−85.68	−83.3	−13.09	−10.71
	(0.10)	(0.09)	(0.01)	(0.01)

Displaced Population

We tested the effects of a higher displacement rate. We assumed 25 percent of the displaced population (estimated to be 720,000 people displaced in addition to the senior population migration assumed in previous runs) leave the San Francisco Bay region in 2018. This is distributed according to each subregion's share of building and content loss (for example, 110,175 people from the east bay, 1,763 people from the north bay, 25,869 people from the west bay, and 42,193 people from the south bay). This displacement could lead to an additional 36,000 job loss, 191,000 population loss, and $4.5 billion in GRP loss in 2018. Because of higher outmigration compared to other subregions, total population in the east bay subregion would not recover to its pre-earthquake level until

Table 26. Employment, population, and gross regional product (GRP) effects with higher outmigration in the HayWired scenario relative to Association of Bay Area Governments Plan Bay Area 2040 projections for the east bay subregion of the San Francisco Bay region, California.

[Negative percentage change in parentheses. East bay subregion refers to Alameda and Contra Costa Counties. Data from the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models Inc.) model version 1.7.8, adjusted control NC3RC1]

Affected categories	2018	2022	2027	2040
Employment	−253,103	−36,186	−5,793	−4,340
	(0.17)	(0.02)	(0.00)	(0.00)
Population	−203,217	−187,147	−99,364	−7,195
	(0.07)	(0.07)	(0.04)	(0.00)
GRP, in billions of 2016 U.S. dollars	−28.98	−5.84	0.02	−0.06
	(0.14)	(0.03)	0.00	(0.00)

Table 27. Employment, population, and gross regional product (GRP) effects with higher outmigration in the HayWired scenario relative to Association of Bay Area Governments Plan Bay Area 2040 projections for the San Francisco Bay region, California.

[Negative percentage change in parenthesis. Data from the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models Inc.) model version 1.7.8, adjusted control NC3RC1]

Affected categories	2018	2022	2027	2040
Employment	−532,202	−73,353	−12,159	−13,665
	(0.11)	(0.01)	(0.00)	(0.00)
Population	−335,925	−344,202	−185,445	−24552
	(0.04)	(0.04)	(0.02)	(0.00)
GRP, in billions of 2016 U.S. dollars	−71.4	−15.708	−0.357	−1.071
	(0.09)	(0.02)	(0.00)	(0.00)

after 2025. By 2040, projected employment and population levels are also lower, with an additional 4,000 jobs lost, and 3,000 population loss; insignificant figures relative to the projections for 2040 (tables 26, 27).

Commuter Resilience

Commuting flexibilities help to mitigate business output losses entered into the final version of the scenario during the first year after the earthquake. Assuming more limited commuting flexibilities occur than previously considered—that is, two-thirds (rather than one-third) of output loss in goods producing, trade and transportation, and utilities industries, and one-half (rather than one-fourth) of output loss in services—total employment loss would increase to around 699,000 jobs and total population loss expand to 188,000 people in 2018, compared to 496,000 jobs lost and 145,000 population loss estimated with the original assumptions. Employment and population loss in the east bay subregion would still be the highest among the four subregions, but the west bay subregion

Table 28. Employment, population, and gross regional product (GRP) effects with worse commuting and telecommuting conditions in the HayWired scenario relative to Association of Bay Area Governments Plan Bay Area 2040 projections for the east bay subregion of the San Francisco Bay region, California.

[Negative percentage change in parentheses. East bay subregion refers to Alameda and Contra Costa Counties. Data from the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models Inc.) model version 1.7.8, adjusted control NC3RC1]

Affected categories	2018	2022	2027	2040
Employment	−277,700	−28,558	−176	–2,933
	(0.18)	(0.02)	(0.00)	(0.00)
Population	−97,954	−126,498	−66,640	−6,954
	(0.04)	(0.05)	(0.02)	(0.00)
GRP, in billions of 2016 U.S. dollars	−32.13	−4.76	0.00	0.00
	(0.16)	(0.02)	0.00	0.00

would have more additional job and population loss than the rest of the region because of worse commuting conditions, reaching a total loss of 235,000 jobs (or 14 percent) and 46,000 people (2 percent). East bay and the total San Francisco Bay region employment would not recover to pre-earthquake levels until after 2022 (tables 28 and 29, respectively). In 2040, the bay region employment is 1,000 jobs below the primary HayWired scenario analysis, whereas the population is above by 200 people.

Table 29. Employment, population, and gross regional product (GRP) effects with worse commuting and telecommuting conditions in the HayWired scenario relative to Association of Bay Area Governments Plan Bay Area 2040 projections for the San Francisco Bay region, California.

[Negative percentage change in parentheses. Data from the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models Inc.) model version 1.7.8, adjusted control NC3RC1]

Affected categories	2018	2022	2027	2040
Employment	−699,374	−59,495	159	−10,290
	(0.14)	(0.01)	0.00	(0.00)
Population	−188,491	−261,456	−138,941	−21,088
	(0.02)	(0.03)	(0.02)	(0.00)
GRP, in billions of 2016 U.S. dollars	−71.4	−97.58	−14.28	1.19
	(0.12)	(0.02)	0.00	(0.00)

Insurance

Rather than assuming insurance is one of the financing sources for the overall investment built into the model, we added insurance spending (15 percent of $85 billion, or $12.75 billion in 2016 U.S. dollars) into the economy separately over 5 years, distributed by 10, 20, 25, 25, and 20 percent from the first to fifth year, respectively. Again, we assumed the distribution is based on the share of building damage related losses ((the sum of building, contents, and inventory repair and replacement costs, relocation costs, income losses, and output losses) by subregion, and three-quarters of the payment would be spent on construction, with one-quarter on the various aforementioned consumer commodities. Because of the stimulus effect from the extra spending, total employment loss would decrease by 13,000 to around 483,000 jobs (10 percent) and total population loss would be reduced to 141,000 people (2 percent) in 2018. Employment and population loss in the east bay subregion would decrease by 8,000 and 2,000, respectively, in 2018. Insurance spending would also help the region recover faster, San Francisco Bay region and east bay subregion employment would recover to pre-earthquake levels in 2021 (tables 30, 31).

Table 30. Employment, population, and gross regional product (GRP) effects with insurance spending in the HayWired scenario relative to Association of Bay Area Governments Plan Bay Area 2040 projections for the east bay subregion of the San Francisco Bay region, California.

[Negative percentage change in parentheses. East bay subregion refers to Alameda and Contra Costa Counties. Data from the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models Inc.) model version 1.7.8, adjusted control NC3RC1]

Affected categories	2018	2022	2027	2040
Employment	−219,870	−13,835	−1,829	−2,465
	(0.15)	0.01)	0.00)	(0.00)
Population	−80,634	−103,476	−56,116	−6,403
	(0.03)	(0.04)	(0.02)	(0.00)
GRP, in billions of 2016 U.S. dollars	−24.99	−3.57	0.00	0.00
	(0.13)	(0.02)	0.00	0.00

Table 31. Employment, population, and gross regional product (GRP) effects with insurance spending in the HayWired scenario relative to Association of Bay Area Governments Plan Bay Area 2040 projections for the San Francisco Bay region, California.

[Negative percentage change in parenthesis. Data from the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models Inc.) model version 1.7.8, adjusted control NC3RC1]

Affected categories	2018	2022	2027	2040
Employment	−482,910	−36,851	−4,169	−9,277
	(0.10)	(0.01)	(0.00)	(0.00)
Population	−141,348	−217,081	−120,764	−20,928
	(0.02)	(0.03)	(0.01)	(0.00)
GRP, in billions of 2016 U.S. dollars	−65.45	−11.9	0	−1.19
	(0.08)	(0.01)	0.00	(0.00)

Government Spending

Rather than assuming Federal, State, and local government spending would cover two-thirds of the uninsured loss, we assumed a worse situation where the Federal Government is not responsive, State and local governments are not able to gather enough resources for the recovery because of financial distress from the earthquake, and government spending in the region would be delayed until years later. Specifically, we made the following changes to the assumptions of the main analysis:

- Only one-third of the uninsured loss would be covered, and
- Government spending and spending in construction would be distributed by 10, 10, 10, 15, 15, 10, 10, 10, and 10 percent over a 9-year period.

As a result of lower level government spending, total employment loss and total population loss would increase by 9,000 to about 503,000 jobs (10 percent) and total 147,000 people (2 percent) in 2018, respectively. Employment and population loss in the east bay subregion would increase by 5,000 and 2,000, respectively, in 2018. Lower government spending would delay the recovery process in the bay region. Bay region and east bay subregion employment would not recover to pre-earthquake levels until after 2024 (tables 32, 33).

Table 32. Employment, population, and gross regional product (GRP) effects with lower government spending in the HayWired scenario relative to Association of Bay Area Governments Plan Bay Area 2040 projections for the east bay subregion of the San Francisco Bay region, California.

[Negative percentage change in parentheses. East bay subregion refers to Alameda and Contra Costa Counties. Data from the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models Inc.) model version 1.7.8, adjusted control NC3RC1]

Affected categories	2018	2022	2027	2040
Employment	−232,259	−39,447	−848	−2,915
	(0.15)	(0.03)	(0.00)	(0.00)
Population	−84,666	−128,497	−69,561	−7,288
	(0.03)	(0.05)	(0.02)	(0.00)
GRP, in billions of 2016 U.S. dollars	−26.11	−5.94	0.00	0.00
	(0.13)	(0.03)	0.00	(0.00)

Table 33. Employment, population, and gross regional product (GRP) effects with lower government spending in the HayWired scenario relative to Association of Bay Area Governments Plan Bay Area 2040 projections for the San Francisco Bay region, California.

[Negative percentage change in parentheses. Data from the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models Inc.) model version 1.7.8, adjusted control NC3RC1]

Affected categories	2018	2022	2027	2040
Employment	−503,920	−80,018	−1,664	−10,006
	(0.10)	(0.02)	(0.00)	(0.00)
Population	−146,947	−253,002	−138,565	−21,947
	(0.02)	(0.03)	(0.02)	(0.00)
GRP, in billions of 2016 U.S. dollars	−67.66	−16.62	1.19	−1.19
	(0.08)	(0.02)	0.00	(0.00)

Technology Sector Exodus

For this sensitivity test, we assumed that the San Francisco Bay region would lose half of the job gain permanently in the internet publishing and broadcasting; internet service providers, search portals, and data processing; and other information services sectors between 2011 and 2015. The Plan Bay Area 2040 REMI-model baseline estimates that these sectors saw an increase of 39,000 jobs in the four subregions (east bay, west bay, north bay, and south bay). We reduced the job increase to about 20,000 for the whole bay region for the rest of the forecasting years (2018–2040). In addition to the job loss assumption in the information subsector, we also reduced the number of jobs in the professional, scientific, and technical services sector proportionally. Based on Quarterly Census of Employment and Wages data from 2011 to 2016 (https://www.bls.gov/cew/#databases) this sector grew by 30 percent in the bay region, with technology-associated computer system design and related services accounting for 60 percent of the growth, whereas growth in other technology-driven professional, scientific, and technical services subsectors, including advertising, public relations, and related services; scientific research and development services; specialized design services; and other professional and technical services accounted for 21 percent of the total job growth in the five-year period. In this analysis, we reduced half of all job growth in the computer system design and related services sector and 50 percent of the growth in other aforementioned professional, scientific, and technical services subsectors; that is, half of the 70 percent job gains in the professional, scientific, and technical services sector permanently, or 41,000 for the bay region using the Association of Bay Area Governments Plan Bay Area 2040 REMI-model baseline. In the Plan Bay Area 2040 REMI model, the north bay subregion experienced negative job change in the professional, scientific, and technical services sector between 2011 and 2015; we kept the north bay subregion unchanged.

The technology sector exodus would remove 229,000 additional jobs, for a total job loss of 725,000 (14 percent), and total population loss would be 201,000 people (3 percent) in 2018. The east bay subregion would lose an additional 39,000 jobs and 12,000 residents in 2018. A technology sector exodus would lead to ripple effects in the economy, decreasing overall recovery and expansion for the full forecast period. San Francisco Bay region and east bay subregion employment would not recover to pre-earthquake levels until after 2028 and would still lag behind the projected employment and population totals in 2040 (tables 34, 35).

Table 34. Employment, population, and gross regional product (GRP) effects with technology sector exodus in the HayWired scenario relative to Association of Bay Area Governments Plan Bay Area 2040 projections for the east bay subregion of the San Francisco Bay region, California.

[Negative percentage change in parentheses. East bay subregion refers to Alameda and Contra Costa Counties. Data from the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models Inc.) model version 1.7.8, adjusted control NC3RC1]

Categories affected	2018	2022	2027	2040
Employment	−266,809	−71,327	−38,839	−45,036
	(0.18)	(0.05)	(0.03)	(0.03)
Population	−95,389	−153,072	−111,624	−68,378
	(0.03)	(0.05)	(0.04)	(0.02)
GRP, in billions of 2016 U.S. dollars	−30.821	−10.591	−4.879	−6.902
	(0.15)	(0.05)	(0.02)	(0.02)

Table 35. Employment, population, and gross regional product (GRP) effects with technology sector exodus in the HayWired scenario relative to Association of Bay Area Governments Plan Bay Area 2040 projections for the San Francisco Bay region, California.

[Negative percentage change in parentheses. Data from the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models Inc.) model version 1.7.8, adjusted control NC3RC1]

Categories affected	2018	2022	2027	2040
Employment	−724,939	−300,263	−226,487	−266,531
	(0.14)	(0.06)	(0.04)	(0.05)
Population	−201,480	−413,822	−384,891	−356,294
	(0.03)	(0.05)	(0.05)	(0.04)
GRP, in billions of 2016 U.S. dollars	−108.171	−59.738	−46.886	−66.759
	(0.13)	(0.07)	(0.04)	(0.05)

Figures 11*A* and 11*B* compare the results of the sensitivity tests for the San Francisco Bay region as a whole. Most changes in post-event factors result in relatively small changes compared to the primary HayWired scenario results. This indicates that many of the effects are captured in the primary analysis. There are a few exceptions. Higher outmigration slightly lowers employment levels and has a somewhat larger effect on population levels for several years after the earthquake. Higher construction costs have a much larger and long-term slowing effect to the economy and population. Because construction costs filter throughout the economy, higher costs can slow down not only the rebuilding effort but also many types of employment growth and the pace of population recovery. A technology sector exodus also exacerbates the employment loss, leading to permanent employment and population net loss compared to the Plan Bay Area 2040 forecast.

The sensitivity tests show some of the uncertainty in assessing possible effects over time. Furthermore, the built-in resiliency of the model may be particularly problematic for understanding the implications for the east bay subregion. Although the whole San Francisco Bay region is strong, diverse, and has a large enough economy that a return close

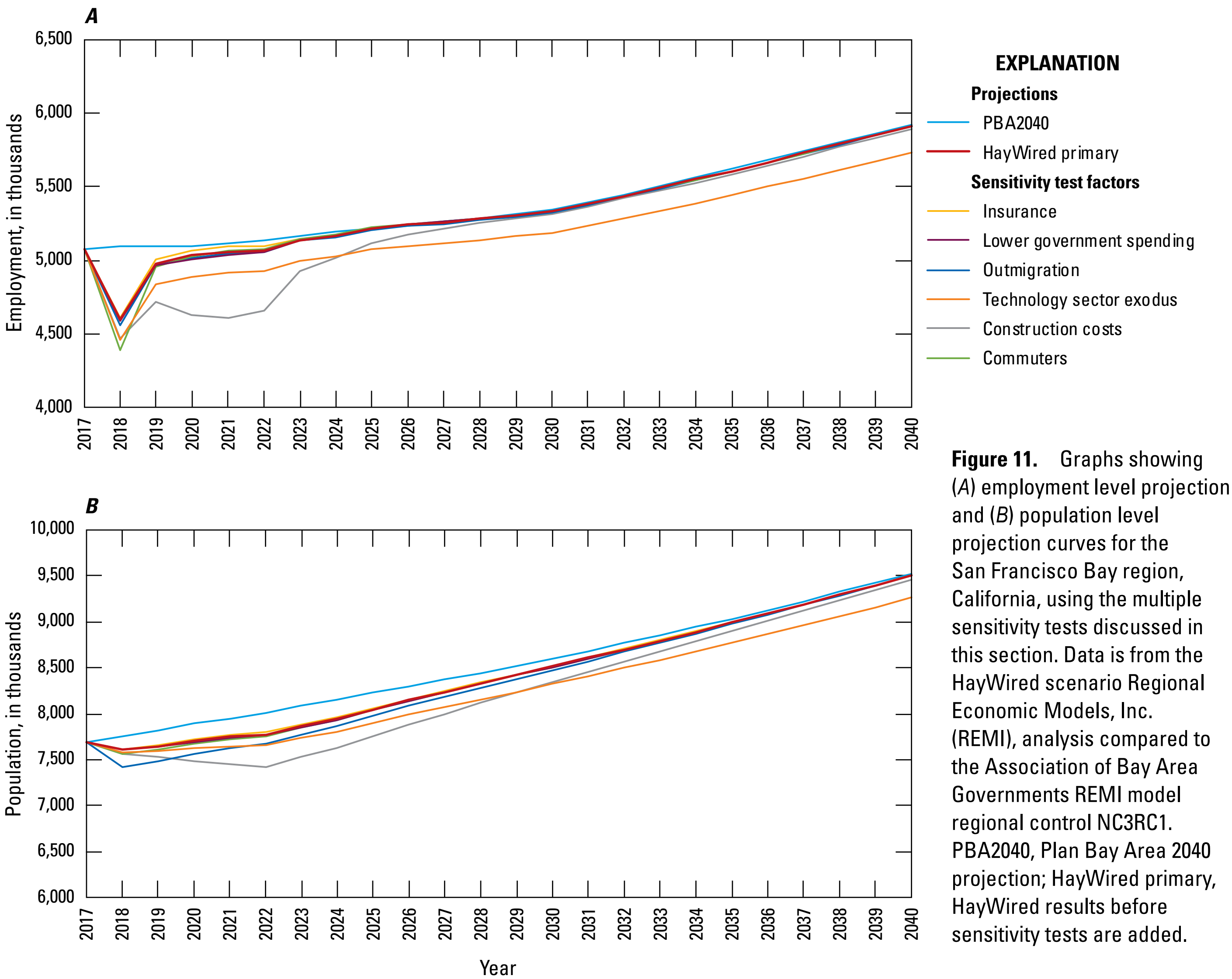


Figure 11. Graphs showing (*A*) employment level projection and (*B*) population level projection curves for the San Francisco Bay region, California, using the multiple sensitivity tests discussed in this section. Data is from the HayWired scenario Regional Economic Models, Inc. (REMI), analysis compared to the Association of Bay Area Governments REMI model regional control NC3RC1. PBA2040, Plan Bay Area 2040 projection; HayWired primary, HayWired results before sensitivity tests are added.

to the previous trend does not seem unreasonable, there could be local effects that are more permanent that are not captured by the model. If infrastructure repair is a lengthy process, the communities in the epicenter of the earthquake are likely to recover much more slowly than the model suggests, even as the region as a whole rebounds. The local- and regional-serving employment base in that area will find it particularly difficult to recover, and even companies with a larger customer base may become much less competitive and may either move or close down. As recovery proceeds, building brand new resources in these heavily damaged places could lead to a boom, but the analysis suggests nothing about the distributional effects of these changes. Without intervention by the public sector (or with the wrong type of intervention), small businesses and lower income and wealth-poor individuals are likely to suffer lifelong negative effects. The effects of displacement on vulnerable populations is addressed in depth by Johnson and others (Population Movements, in prep. [planned to be published as a part of this volume]), whereas neighborhood economic effects are addressed by Wein, Belzer, and others (this volume).

Policy Implications

Public policy will be a critical aspect of addressing the economic effects of a HayWired scenario-like event. In light of the results of the HayWired REMI analysis, some public policies that focus on the following areas may reduce and (or) mitigate the effects of a major earthquake through investments or planning before it occurs and through post-event responses.

- Direct output loss from building damage may be reduced through building design and retrofits that reduce the amount of damage that occurs to both residential and nonresidential space.

- The duration and total effects of output loss from building damage and inventory loss can be reduced by cooperative responses among businesses and neighbors and even between heavily and less affected areas. Efforts to build networking ties before the event can make it easier to develop these cooperative responses in a crisis period.
- Output loss and associated effects caused by fire after the earthquake can be mitigated by making buildings and neighborhoods more fire resistant to any extent. This will reduce not only earthquake related hazards but those related to wild land and urban wildfires. The effects of fire can be further reduced if cities, counties, and the State have identified means for fighting fires in cases where water delivery has been interrupted.
- The vulnerability of local serving businesses like food services, retail, and health care can have long-term effects on neighborhood resilience. Planning for neighborhood response and business relocation in advance, as well as providing temporary facilities and support services for businesses after the event, can help mitigate the otherwise widespread losses expected in these sectors.
- The increased demand for construction workers coincides with direct effects to the sector. Also, there is currently an urgency for construction capability in the San Francisco Bay region to build more housing and for funded and approved transportation infrastructure projects. Loss of construction capacity or increases in construction costs will slow the ability to recover. Long-term planning for resilience in the construction industry, by major employers, trade organizations, educational institutions, and local, State and Federal government can improve the industry's ability to respond not only to catastrophic events but also to the wide swings experienced by the industry in business cycles.
- The role of major employers in all sectors is also of key importance in terms of their ability to provide support for their larger workforce and their role in the regional economy. Inclusion of major employers such as those in the technology sector at all stages—in advanced planning, initial responses, and recovery—can contribute to the success of recovery efforts by augmenting the resources available when most needed and also ensuring that employees, suppliers, and other linked sectors are informed about immediate conditions and resources as well as choices that may have long-term effects during an event.
- The quick recovery in overall employment depends heavily on investment for rebuilding homes, nonresidential buildings, and infrastructure. The public sector plays a critical role in this by not only providing a portion of the funding but by also providing the means for clearance of debris, safety checks, and issuance of new permits. Without the robust level of recovery spending assumed in this analysis, the east bay subregion would require at least 5 years to reach within 1 percent of the projected employment levels.
- Investment in recovery is not only the responsibility of the public sector. In the sensitivity analysis, private insurance payments have a relatively small effect on the outcome because these payments cover such a small share of the total damage. Were a larger share of homes and buildings covered by insurance, recovery would be better resourced, and displacement and outmigration could be less. Judging from past experience, close cooperation among assistance agencies, such as FEMA, and the California Governor's Office of Emergency Services and private insurers may be needed to ensure the timely consideration and payment of claims.
- Restoration of the telecommunications sector is also a major factor in allowing many economic sectors to fully restore their operations. As seen in the sensitivity tests, if networking through telecommunications cannot be achieved, then the commute effects could be much more severe.
- Temporary housing services will be crucial in maintaining the labor force needed to keep ongoing businesses in operation and provide the labor force needed for reconstruction. Identification of successful efforts in previous disasters may make it easier to respond effectively after an event.
- Expedited permitting will be needed to allow rebuilding to happen in the time period shown in the model, whereas advanced planning for future contingencies would better prepare jurisdictions to address rebuilding efforts from a comprehensive perspective and effective retrofit programs could reduce displacement in the first place.
- Advanced planning to better address the effects of a major seismic event should address the likely issues faced by vulnerable populations. Clearance of damaged neighborhoods can also lead to clearance of communities and lower income renter households. Advanced planning may make it more likely that assistance is available to displaced households and could also require that the displaced populations be given the opportunity to participate in planning for rebuilding. This will affect who stays and who leaves the region and the level of resilience of existing businesses. This type of planning can happen as a mitigating pre-event approach, rather than only relying on it as an approach to react to the event.

Future Research with REMI Modeling

Using the REMI model to examine the HayWired scenario made it possible to explore how a range of different negative effects or different recovery investments could affect the San Francisco Bay region economy. With a modeling approach like REMI, there is an unlimited number of tests that could be run and effects examined. Although the descriptions above may seem exhaustive, there are additional areas of research with the model that could be informative. We mention a few of these here.

First, the analysis relies on Hazus for output estimates because the model lacks a complete link between the loss of capital stock and economic and population effects. A closer link between capital losses and the economic and demographic impacts would improve the analysis. A few additional directions to explore include, for one, considering the unreconstructed capital stock lost as a factor to determine the residential and nonresidential investment totals. Second, population displacement from damaged buildings was entered in an artificial way in this analysis. Further experiments with levers in the model to reflect this effect could include the use of residential capital stock or investment, more extreme price changes, or additional ways to estimate the change in the amenity variable. Third, changes in public revenues could be explored further by inserting changes in Federal spending, incorporating shifts in local government revenues, and by including property and sales taxes in the model.

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Appendixes 1–6

Appendix 1

Table 1.1 shows the sector description for each Hazus occupancy class and North American Industry Classification System (NAICS) codes included in each Hazus sector. Using the corresponding relation between NAICS and Hazus occupancy class from this table, we can map Regional Economic Models, Inc., (REMI) sectors into each Hazus occupancy class, shown in table 1.2, which would then be used to summarize output loss by REMI sector using Hazus output.

Table 1.1. Industry sector with the corresponding Hazus occupancy class and North American Industry Classification System (NAICS) code.

Sector description	NAICS code	HAZUS occupancy class
Agriculture, forestry, fishing and hunting	11	AGR1
Retail trade	44–45	COM1
Wholesale trade, warehousing and storage	42	COM2
Truck transportation	484	COM2
Repair and maintenance	811	COM3
Personal services / private households	812, 814	COM3
Electric power generation, transmission, and distribution	2211	COM4
Natural gas distribution	2212	COM4
Water, sewage, and other systems	2213	COM4
Air transportation	481	COM4
Rail transportation	482	COM4
Water transportation	483	COM4
Transit and ground passengers	485	COM4
Pipeline transportation	486	COM4
Sightseeing transportation	487 and 488	COM4
Couriers and messengers	492	COM4
Internet publishing and broadcasting	51913	COM4
Data processing, hosting, and related services	518	COM4
Other information services	51911–2	COM4
Computer systems design and related services	5415	COM4
Professional scientific and technical services	54 except for 5415	COM4
Other business services	55, 56	COM4
Finance, insurance, real estate, and leasing	52, 53	COM4, COM5
Ambulatory health care and hospitals	621, 622	COM6, COM7
Telecommunications	517	COM8
Arts, entertainment, and recreation	711–713, 722	COM8
Educational services	6111, 6112–3, 6114–7	EDU1, EDU2
Government and nonNAICS	n.a.	GOV1, GOV2
Heavy industry	313, 321, 322, 327, 332,333, 336	IND1
Light industry	314, 315, 316, 323, 326,part of 334 (except for334111, 334112,334411, 334412,334413), 335, 337, 339,511, 516	IND2
Publishing, motion picture, and broadcasting	511, 512, 515	IND2, COM4
Petroleum refineries	32411	IND3
Food, drug, and chemicals	311, 312, 324 except for32411, 325	IND3
Oil and gas extraction	211	IND4
Coal mining	2121	IND4

Table 1.1. Tabulated description of each sector with the corresponding Hazards U.S. (HAZUS) occupancy class and North American Industry Classification System (NAICS) code—Continued.

Sector description	NAICS code	HAZUS occupancy class
Other mining	212–213 except for 2121	IND4
Primary metal manufacturing	331	IND4
Electronic computer manufacturing	334111	IND5
Computer storage device manufacturing	334112	IND5
Semiconductor and related device manufacturing	334413	IND5
Other high technology related manufacturing	334411, 334412	IND5
Construction		IND6
Religious, grantmaking, and similar organizations	813	REL1
Imputed rental value for owner-occupied dwellings	n.a.	RES1–RES3
Accommodations	721	RES4
Nursing home/social assistance	623, 624	RES6, COM3

Table 1.2. Tabulated description of Regional Economic Models, Inc. (REMI) 70 sectors and corresponding Hazus occupancy class and North American Industry Classification System (NAICS) code.

REMI sectors	NAICS code	HAZUS occupancy class
Forestry and logging; fishing, hunting, and trapping	113-114	AGR1
Agriculture and forestry support activities	115	AGR1
Oil and gas extraction	211	IND4
Mining (except oil and gas)	212	IND4
Support activities for mining	213	IND4
Utilities	22	COM4
Construction	23	IND6
Wood product manufacturing	321	IND1
Nonmetallic mineral product manufacturing	327	IND1
Primary metal manufacturing	331	IND4
Fabricated metal product manufacturing	332	IND1
Machinery manufacturing	333	IND1
Computer and electronic product manufacturing	334	IND2
Electrical equipment and appliance manufacturing	335	IND2
Motor vehicles, bodies and trailers, and parts manufacturing	3361-3363	IND1
Other transportation equipment manufacturing	3364-3369	IND1
Furniture and related product manufacturing	337	IND2
Miscellaneous manufacturing	339	IND2
Food manufacturing	311	IND3
Beverage and tobacco product manufacturing	312	IND3
Textile mills; textile product mills	313-314	IND1, IND2
Apparel, leather and allied product manufacturing	315-316	IND2
Paper manufacturing	322	IND1
Printing and related support activities	323	IND2
Petroleum and coal products manufacturing	324	IND3
Chemical manufacturing	325	IND3

Table 1.2. Tabulated description of Regional Economic Models, Inc. (REMI) 70 sectors and corresponding Hazus occupancy class and North American Industry Classification System (NAICS) code.—Continued

REMI sectors	NAICS code	HAZUS occupancy class
Plastics and rubber product manufacturing	326	IND2
Wholesale trade	42	COM2
Retail trade	44-45	COM1
Air transportation	481	COM4
Rail transportation	482	COM4
Water transportation	483	COM4
Truck transportation	484	COM2
Couriers and messengers	492	COM4
Transit and ground passenger transportation	485	COM4
Pipeline transportation	486	COM4
Scenic and sightseeing transportation and support activities for transportation	487-488	COM4
Warehousing and storage	493	COM3
Publishing industries, except internet	511	IND2
Motion picture and sound recording industries	512	IND2, COM4
Internet publishing and broadcasting; ISPs, search portals, and data processing; other information services	518-519	COM4
Broadcasting, except internet	515	IND2, COM4
Telecommunications	517	COM8
Monetary authorities and other credit institutions	521,522,525	COM4, COM5
Securities, commodity contracts, investments	523	COM4, COM5
Insurance carriers and related activities	524	COM4, COM5
Real estate	531	COM4, COM5
Rental and leasing services; lessors of nonfinancial intangible assets	532,533	COM4, COM5
Professional, scientific, and technical services	54	COM4
Management of companies and enterprises	55	COM4
Administrative and support services	561	COM4
Waste management and remediation services	562	COM4
Educational services; private	61	EDU1, EDU2
Ambulatory health care services	621	COM6, COM7
Hospitals; private	622	COM6, COM7
Nursing and residential care facilities	623	RES6, COM3
Social assistance	624	RES6, COM3
Performing arts and spectator sports	711	COM8
Museums, historical sites, zoos, and parks	712	COM8
Amusement, gambling, and recreation	713	COM8
Accommodation	721	RES4
Food services and drinking places	722	COM8
Repair and maintenance	811	COM3
Personal and laundry services	812	COM3
Membership associations and organizations	813	REL1

Table 1.2. Tabulated description of Regional Economic Models, Inc. (REMI) 70 sectors and corresponding Hazus occupancy class and North American Industry Classification System (NAICS) code.—Continued

REMI sectors	NAICS code	HAZUS occupancy class
Private households	814	COM3
State and local government	NA	GOV1, GOV2
Federal civilian	NA	GOV1, GOV2
Federal military	NA	GOV1, GOV2
Farm	111-112	AGR1

For each subregion, we first calculated the share of output loss for each Hazus occupancy class in each year of the first three years where output loss is estimated. We then determined that the share of loss for each REMI sector was equal to the share of loss for the occupancy class the sector belongs to. For example, both telecommunication (NAICS 517) and performing arts and spectator sports (NAICS 711) are in Hazus occupancy class COM8. Therefore, shares of output loss in these two sectors are the same, even if the activities are significantly different. In the case where a sector is mapped to two Hazus occupancy classes, the share of output loss for this sector equals the combined share of loss as calculated for those occupancy classes. Next, we applied the share of loss calculated for each REMI sector in each year to REMI-projected 2018 output to determine the dollar loss which was then put in as changes in REMI output variables. Table 1.3 shows the results of translation.

Table 1.3. San Francisco Bay region, California, industry direct output loss by year in the HayWired scenario using Regional Economic Models, Inc., output baseline.

[Sectors are sorted by first year loss amount. Data from Association of Bay Area Governments calculated using Hazus loss by occupancy class results]

Sector	Value of output loss, in millions of 2016 U.S. dollars			Loss of 2018 industry output, in percent		
	1st year	2d year	3d year	1st year	2d year	3d year
Petroleum and coal products manufacturing	2016.0	2.1	0.0	4	0	0
Food services and drinking places	1900.5	77.3	0.0	9	0	0
Ambulatory health care services	1770.4	89.7	0.0	6	0	0
Machinery manufacturing	1594.2	4.1	0.0	12	0	0
Real estate	1277.6	34.1	0.0	1	0	0
Professional, scientific, and technical services	1237.0	49.6	0.0	1	0	0
Computer and electronic product manufacturing	1117.1	19.9	0.0	1	0	0
Hospitals; private	1073.7	72.2	0.0	6	0	0
Construction	848.9	5.1	0.0	2	0	0
Wholesale trade	795.0	17.3	0.0	2	0	0
Retail trade	736.8	12.6	0.0	2	0	0
Fabricated metal product manufacturing	710.5	1.7	0.0	11	0	0
Motor vehicles, bodies and trailers, and parts manufacturing	635.9	0.6	0.0	22	0	0
Performing arts and spectator sports	544.4	19.7	0.0	9	0	0
Other transportation equipment manufacturing	505.6	2.3	0.0	9	0	0
Accommodation	493.8	55.9	0.0	5	1	0

Table 1.3. San Francisco Bay region, California, industry direct output loss by year in the HayWired scenario using Regional Economic Models, Inc., output baseline.—Continued

Sector	Value of output loss, in millions of 2016 U.S. dollars			Loss of 2018 industry output, in percent		
	1st year	2d year	3d year	1st year	2d year	3d year
Chemical manufacturing	416.0	2.6	0.0	1	0	0
Monetary authorities and other credit institutions	385.9	10.5	0.0	1	0	0
Oil and gas extraction	365.1	0.3	0.0	8	0	0
Internet publishing and broadcasting; ISPs, search portals, and data processing; other information services	358.7	50.6	0.0	0	0	0
Publishing industries, except internet	349.9	4.9	0.0	1	0	0
Amusement, gambling, and recreation	326.1	11.1	0.0	9	0	0
Management of companies and enterprises	316.1	4.5	0.0	1	0	0
Nonmetallic mineral product manufacturing	314.7	0.6	0.0	12	0	0
Food manufacturing	302.2	0.8	0.0	2	0	0
Administrative and support services	276.8	8.9	0.0	1	0	0
Paper manufacturing	222.6	0.4	0.0	16	0	0
Primary metal manufacturing	206.9	0.3	0.0	5	0	0
Social assistance	189.3	17.8	3.8	2	0	0
Beverage and tobacco product manufacturing	178.9	0.6	0.0	1	0	0
Insurance carriers and related activities	176.7	2.7	0.0	1	0	0
Miscellaneous manufacturing	176.3	0.8	0.0	2	0	0
Utilities	159.1	2.5	0.0	1	0	0
Nursing and residential care facilities	151.4	13.4	3.1	3	0	0
Repair and maintenance	143.7	7.2	0.0	2	0	0
Securities, commodity contracts, investments	138.3	5.2	0.0	0	0	0
Wood product manufacturing	134.1	0.3	0.0	11	0	0
Rental and leasing services; lessors of nonfinancial intangible assets	99.4	2.4	0.0	1	0	0
Personal and laundry services	95.0	4.7	0.0	2	0	0
Truck transportation	93.9	1.4	0.0	2	0	0
Museums, historical sites, zoos, and parks	62.5	2.4	0.0	6	0	0
Air transportation	59.6	0.8	0.0	1	0	0
Waste management and remediation services	59.1	0.9	0.0	1	0	0
Motion picture and sound recording industries	57.6	0.5	0.0	1	0	0
Electrical equipment and appliance manufacturing	54.4	0.4	0.0	2	0	0
Couriers and messengers	46.7	0.6	0.0	2	0	0
Printing and related support activities	41.0	0.2	0.0	2	0	0

Table 1.3. San Francisco Bay region, California, industry direct output loss by year in the HayWired scenario using Regional Economic Models, Inc., output baseline.—Continued

Sector	Value of output loss, in millions of 2016 U.S. dollars			Loss of 2018 industry output, in percent		
	1st year	2d year	3d year	1st year	2d year	3d year
Water transportation	40.0	0.1	0.0	2	0	0
Plastics and rubber product manufacturing	35.9	0.1	0.0	3	0	0
Warehousing and storage	33.8	0.6	0.0	4	0	0
Telecommunications	33.2	0.0	0.0	0	0	0
Educational services; private	31.3	3.9	0.0	0	0	0
Broadcasting, except Internet	30.2	0.5	0.0	1	0	0
Scenic and sightseeing transportation and support activities for transportation	30.1	0.4	0.0	1	0	0
Furniture and related product manufacturing	24.9	0.1	0.0	2	0	0
Membership associations and organizations	21.5	2.0	0.0	0	0	0
Private households	19.9	0.9	0.0	2	0	0
Textile mills; textile product mills	17.5	0.1	0.0	6	0	0
Mining (except oil and gas)	16.9	0.0	0.0	3	0	0
Rail transportation	12.8	0.2	0.0	2	0	0
Transit and ground passenger transportation	12.0	0.2	0.0	1	0	0
Pipeline transportation	11.9	0.1	0.0	2	0	0
Apparel, leather and allied product manufacturing	5.5	0.0	0.0	2	0	0
Support activities for mining	0.7	0.0	0.0	1	0	0
Agriculture and forestry support activities	0.1	0.0	0.0	0	0	0
Forestry and logging; fishing, hunting, and trapping	0.0	0.0	0.0	0	0	0

Appendix 2

Table 2.1. San Francisco Bay region, California, total output loss by private industry sector in 2018.

[These output losses include the direct output loss calculated in Hazus from building damage as well as additional output loss the model identifies in linked industries and because of the initial output-related population losses. Output losses and sorted by 1st year loss. Data generated using the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models Inc.) model analysis from 2018 (this study)]

Category	Output loss, in millions of 2016 U.S. dollars	Share of output loss, in percent
Real estate	4095.2	2.8
Professional, scientific, and technical services	3304.4	2.3
Construction	3053.1	7.4
Ambulatory health care services	2625.5	8.4
Petroleum and coal products manufacturing	2485.8	5.2
Food services and drinking places	2315.7	10.4
Retail trade	1958.7	4.0
Wholesale trade	1897.3	4.0
Machinery manufacturing	1830.1	13.9
Monetary authorities and other credit institutions	1694.1	3.8
Hospitals	1349.2	6.9
Computer and electronic product manufacturing	1308.4	1.0
Administrative and support services	1133.2	3.9
Management of companies and enterprises	969.1	4.1
Fabricated metal product manufacturing	951.2	15.4
Securities, commodity contracts, investments	893.9	2.9
Chemical manufacturing	841.8	1.9
Telecommunications	806.7	2.7
Motor vehicles, bodies and trailers, and parts manufacturing	771.2	26.3
Performing arts and spectator sports	770.4	13.3
Accommodation	700.8	6.8
Publishing industries, except internet	674.6	1.5
Internet publishing and broadcasting; ISPs, search portals, and data processing; other information services	673.4	0.7
Insurance carriers and related activities	624.5	3.5
Food manufacturing	604.6	4.5
Oil and gas extraction	594.6	13.5
Utilities	562.0	4.2
Other transportation equipment manufacturing	558.9	9.7
Nonmetallic mineral product manufacturing	453.4	16.8
Primary metal manufacturing	445.4	11.7

Table 2.1. San Francisco Bay region, California, total output loss by private industry sector in 2018.—Continued

Category	Output loss, in millions of 2016 U.S. dollars	Share of output loss, in percent
Amusement, gambling, and recreation	410.2	11.0
Beverage and tobacco product manufacturing	376.0	1.3
Repair and maintenance	363.9	6.1
Rental and leasing services; lessors of nonfinancial intangible assets	358.3	3.1
Social assistance	342.5	4.4
Paper manufacturing	273.8	19.7
Miscellaneous manufacturing	271.0	3.0
Personal and laundry services	251.1	5.1
Nursing and residential care facilities	237.3	4.2
Truck transportation	233.0	5.0
Educational services	223.8	2.0
Membership associations and organizations	221.2	3.3
Wood product manufacturing	206.2	16.4
Waste management and remediation services	171.6	4.3
Air transportation	169.5	2.0
Broadcasting, except internet	120.9	4.3
Couriers and messengers	115.8	4.2
Electrical equipment and appliance manufacturing	100.3	3.0
Motion picture and sound recording industries	96.0	2.4
Printing and related support activities	94.7	4.3
Plastics and rubber product manufacturing	94.6	7.5
Scenic and sightseeing transportation; support activities for transportation	83.9	3.5
Museums, historical sites, zoos, and parks	80.6	7.3
Warehousing and storage	75.2	8.8
Furniture and related product manufacturing	63.8	5.3
Water transportation	63.2	3.8
Private households	47.6	5.1
Transit and ground passenger transportation	47.2	4.2
Mining (except oil and gas)	36.3	7.5
Pipeline transportation	33.2	4.8
Rail transportation	30.3	4.7
Textile mills; textile product mills	25.1	8.3
Apparel manufacturing; leather and allied product manufacturing	6.9	2.3
Support activities for mining	4.6	5.2
Forestry and logging; fishing, hunting, and trapping	4.2	4.1

Appendix 3

Table 3.1. Revised San Francisco Bay region, California, output loss from building damage and transportation network interruption in the HayWired scenario by year using Regional Economic Models, Inc., output baseline.

[Sectors are sorted by first year loss]

Sector	Value of output loss			Loss of 2018 industry output, in percent		
	1st year	2d year	3d year	1st year	2d year	3d year
Professional, scientific, and technical services	4416.3	49.6	0.0	3	0	0
Real estate	4250.9	34.1	0.0	3	0	0
Computer and electronic product manufacturing	3674.9	19.9	0.0	3	0	0
Food services and drinking places	3141.3	77.3	0.0	14	0	0
Ambulatory health care services	2696.0	89.7	0.0	9	0	0
Internet publishing and broadcasting; ISPs, search portals, and data processing; other information services	2693.8	50.6	0.0	3	0	0
Machinery manufacturing	2490.4	4.1	0.0	19	0	0
Petroleum and coal products manufacturing	2386.6	2.1	0.0	5	0	0
Retail trade	2104.6	12.6	0.0	4	0	0
Wholesale trade	2060.3	17.3	0.0	4	0	0
Construction	1856.2	5.1	0.0	5	0	0
Hospitals; private	1673.1	72.2	0.0	9	0	0
Chemical manufacturing	1656.4	2.6	0.0	4	0	0
Publishing industries, except internet	1354.1	4.9	0.0	3	0	0
Monetary authorities and other credit institutions	1329.6	10.5	0.0	3	0	0
Fabricated metal product manufacturing	1094.9	1.7	0.0	18	0	0
Other transportation equipment manufacturing	1052.8	2.3	0.0	18	0	0
Accommodation	934.6	55.9	0.0	9	1	0
Securities, commodity contracts, investments	907.5	5.2	0.0	3	0	0
Administrative and support services	887.7	8.9	0.0	3	0	0
Performing arts and spectator sports	877.9	19.7	0.0	15	0	0
Management of companies and enterprises	817.0	4.5	0.0	3	0	0
Motor vehicles, bodies and trailers, and parts manufacturing	691.6	0.6	0.0	24	0	0
Insurance carriers and related activities	542.8	2.7	0.0	3	0	0
Amusement, gambling, and recreation	525.0	11.1	0.0	14	0	0
Food manufacturing	514.1	0.8	0.0	4	0	0
Telecommunications	485.4	0.0	0.0	2	0	0
Beverage and tobacco product manufacturing	467.3	0.6	0.0	2	0	0
Nonmetallic mineral product manufacturing	448.9	0.6	0.0	17	0	0
Utilities	430.6	2.5	0.0	3	0	0

Table 3.1. Revised San Francisco Bay region, California, output loss from building damage and transportation network interruption in the HayWired scenario by year using Regional Economic Models, Inc., output baseline.—Continued

Sector	Value of output loss			Loss of 2018 industry output, in percent		
	1st year	2d year	3d year	1st year	2d year	3d year
Oil and gas extraction	417.4	0.3	0.0	9	0	0
Social assistance	358.2	17.8	3.8	5	0	0
Rental and leasing services; lessors of nonfinancial intangible assets	340.4	2.4	0.0	3	0	0
Miscellaneous manufacturing	302.4	0.8	0.0	3	0	0
Paper manufacturing	290.0	0.4	0.0	21	0	0
Primary metal manufacturing	284.4	0.3	0.0	7	0	0
Air transportation	268.2	0.8	0.0	3	0	0
Nursing and residential care facilities	264.5	13.4	3.1	5	0	0
Repair and maintenance	263.8	7.2	0.0	4	0	0
Educational services; private	221.6	3.9	0.0	2	0	0
Personal and laundry services	208.9	4.7	0.0	4	0	0
Truck transportation	193.6	1.4	0.0	4	0	0
Wood product manufacturing	191.5	0.3	0.0	15	0	0
Motion picture and sound recording industries	143.2	0.5	0.0	4	0	0
Membership associations and organizations	132.8	2.0	0.0	2	0	0
Waste management and remediation services	132.8	0.9	0.0	3	0	0
Museums, historical sites, zoos, and parks	126.8	2.4	0.0	11	0	0
Electrical equipment and appliance manufacturing	110.6	0.4	0.0	3	0	0
Couriers and messengers	96.8	0.6	0.0	4	0	0
Broadcasting, except internet	89.1	0.5	0.0	3	0	0
Scenic and sightseeing transportation and support activities for transportation	80.3	0.4	0.0	3	0	0
Printing and related support activities	76.7	0.2	0.0	3	0	0
Water transportation	69.9	0.1	0.0	4	0	0
Plastics and rubber product manufacturing	47.3	0.1	0.0	4	0	0
Warehousing and storage	47.2	0.6	0.0	6	0	0
Furniture and related product manufacturing	41.0	0.1	0.0	3	0	0
Private households	40.8	0.9	0.0	4	0	0
Transit and ground passenger transportation	34.4	0.2	0.0	3	0	0
Textile mills; textile product mills	29.2	0.1	0.0	10	0	0
Pipeline transportation	26.1	0.1	0.0	4	0	0
Rail transportation	24.6	0.2	0.0	4	0	0
Mining (except oil and gas)	23.1	0.0	0.0	5	0	0
Apparel, leather and allied product manufacturing	10.5	0.0	0.0	3	0	0
Agriculture and forestry support activities	2.8	0.0	0.0	1	0	0
Support activities for mining	2.7	0.0	0.0	3	0	0
Forestry and logging; fishing, hunting, and trapping	1.9	0.0	0.0	2	0	0

Appendix 4

Table 4.1. San Francisco Bay region, California, total output loss from combined building and transportation effects in the HayWired scenario by private industry sector in 2018.

[Categories are sorted by 1st year loss. Data generated using the Association of Bay Area Governments Planning and Research Department (2016) REMI (Regional Economic Models, Inc.) model analysis from 2018 (this study)]

Category	Output loss, in millions of 2016 U.S dollars	Share of output loss, in percent
Real estate	10,934.9	7.6
Professional, scientific, and technical services	9,531.9	6.5
Construction	6,772.3	6.5
Retail trade	4,993.2	10.3
Monetary authorities and other credit institutions	4,652.9	10.4
Ambulatory health care services	4,623.2	14.9
Wholesale trade	4,517.2	9.4
Food services and drinking places	4,174.5	18.7
Computer and electronic product manufacturing	4,091.2	3.2
Petroleum and coal products manufacturing	3,562.9	7.4
Internet publishing and broadcasting; ISPs, search portals, and data processing; other information services	3,502.2	3.4
Administrative and support services	2,998.8	10.2
Machinery manufacturing	2,954.8	22.4
Securities, commodity contracts, investments	2,853.6	9.2
Chemical manufacturing	2,716.8	6.3
Telecommunications	2,425.2	8.0
Hospitals	2,303.8	11.8
Management of companies and enterprises	2,245.5	9.5
Publishing industries, except Internet	2,192.0	4.9
Insurance carriers and related activities	1,644.6	9.2
Fabricated metal product manufacturing	1,562.5	25.2
Accommodation	1,469.7	14.2
Performing arts and spectator sports	1,389.9	24.0
Utilities	1,278.1	9.6
Other transportation equipment manufacturing	1,173.3	20.3
Food manufacturing	1,125.7	8.3
Rental and leasing services; lessors of nonfinancial intangible assets	959.1	8.4
Beverage and tobacco product manufacturing	903.2	3.1
Motor vehicles, bodies and trailers, and parts manufacturing	897.3	30.6
Oil and gas extraction	753.3	17.1
Repair and maintenance	737.8	12.4
Amusement, gambling, and recreation	731.9	19.6
Nonmetallic mineral product manufacturing	727.1	26.9

Table 4.1. San Francisco Bay region, California, total output loss from combined building and transportation effects in the HayWired scenario by private industry sector in 2018.—Continued

Category	Output loss, in millions of 2016 U.S dollars	Share of output loss, in percent
Social assistance	718.8	9.3
Educational services	687.8	6.1
Primary metal manufacturing	655.7	17.3
Membership associations and organizations	610.5	9.0
Personal and laundry services	574.8	11.6
Miscellaneous manufacturing	529.6	5.9
Air transportation	523.6	6.3
Truck transportation	474.8	10.2
Nursing and residential care facilities	457.0	8.2
Paper manufacturing	380.8	27.5
Waste management and remediation services	377.2	9.4
Wood product manufacturing	321.3	25.6
Broadcasting, except Internet	317.7	11.4
Couriers and messengers	260.6	9.5
Motion picture and sound recording industries	235.6	5.9
Scenic and sightseeing transportation; support activities for transportation	210.6	8.8
Electrical equipment and appliance manufacturing	208.3	6.3
Printing and related support activities	204.7	9.2
Museums, historical sites, zoos, and parks	166.6	15.1
Plastics and rubber product manufacturing	145.2	11.5
Water transportation	126.1	7.6
Furniture and related product manufacturing	122.6	10.3
Warehousing and storage	121.4	14.3
Transit and ground passenger transportation	117.8	10.3
Private households	105.9	11.3
Pipeline transportation	67.8	9.8
Rail transportation	57.1	8.9
Mining (except oil and gas)	55.9	11.5
Textile mills; textile product mills	45.2	14.8
Apparel manufacturing; leather and allied product manufacturing	14.3	4.7
Support activities for mining	13.1	4.5
Forestry and logging; fishing, hunting, and trapping	9.5	8.9

Appendix 5

Table 5.1. San Francisco Bay region, California, total employment net change.

[Year 1 of the scenario is 2018, year 5 is 2022, year 10 is 2027, and year 23 is 2040]

Category	2018	2022	2027	2040
Forestry and logging; Fishing, hunting, and trapping	−62	−1	2	−1
Agriculture and forestry support activities	−252	−7	−2	−5
Oil and gas extraction	−802	45	68	−5
Mining (except oil and gas)	−522	9	30	−7
Support activities for mining	−283	11	39	−6
Utilities	−1,354	−156	−43	−27
Construction	−31,641	−1,406	6,416	−294
Wood product manufacturing	−1,159	−86	42	−3
Nonmetallic mineral product manufacturing	−2,152	−28	71	−11
Primary metal manufacturing	−704	8	8	−2
Fabricated metal product manufacturing	−5,731	56	78	−18
Machinery manufacturing	−5,292	−14	16	−16
Computer and electronic product manufacturing	−3,084	821	269	−47
Electrical equipment and appliance manufacturing	−492	24	10	−4
Motor vehicles, bodies and trailers, and parts manufacturing	−1,056	−13	5	−5
Other transportation equipment manufacturing	−2,345	13	2	−6
Furniture and related product manufacturing	−613	−10	16	−6
Miscellaneous manufacturing	−1,324	68	25	−12
Food manufacturing	−2,486	−233	−102	−40
Beverage and tobacco product manufacturing	−750	−70	−32	−24
Textile mills; Textile product mills	−215	23	8	−1
Apparel manufacturing; Leather and allied product manufacturing	−165	242	79	3
Paper manufacturing	−724	−1	−1	−2
Printing and related support activities	−1,010	−25	0	−9
Petroleum and coal products manufacturing	−482	45	46	2
Chemical manufacturing	−1,305	29	11	−18
Plastics and rubber product manufacturing	−509	4	8	−3
Wholesale trade	−15,094	−131	−85	−221
Retail trade	−43,420	−750	−633	−1,018
Air transportation	−1,328	56	42	−22
Rail transportation	−119	3	4	−1
Water transportation	−194	5	5	−4
Truck transportation	−2,237	14	33	−26
Couriers and messengers	−1,761	36	24	−11

Table 5.1. San Francisco Bay region, California, total employment net change. —Continued

Category	2018	2022	2027	2040
Transit and ground passenger transportation	−1,958	211	65	−56
Pipeline transportation	−81	−7	0	−1
Scenic and sightseeing transportation; support activities for transportation	−1,762	133	88	−19
Warehousing and storage	−1,412	−24	14	−18
Publishing industries, except Internet	−1,744	26	15	−34
Motion picture and sound recording industries	−742	77	41	−5
Internet publishing and broadcasting; ISPs, search portals, and data processing; other information services	−3,064	0	−20	−53
Broadcasting, except Internet	−1,063	−37	−8	−21
Telecommunications	−2,525	−114	−28	−77
Monetary authorities and other credit institutions	−13,005	−2,355	90	−222
Securities, commodity contracts, investments	−6,516	−86	94	−72
Insurance carriers and related activities	−6,233	−817	−138	−199
Real estate	−24,108	−23,162	−796	−892
Rental and leasing services; lessors of nonfinancial intangible assets	−1,864	−2	35	−23
Professional, scientific, and technical services	−44,184	−2,479	−7	−806
Management of companies and enterprises	−7,016	44	68	−53
Administrative and support services	−32,247	−3,143	−71	−418
Waste management and remediation services	−1,578	−373	−23	−31
Educational services	−9,126	−769	−193	−352
Ambulatory health care services	−23,390	−713	−696	−972
Hospitals	−11,009	−1,170	−778	−451
Nursing and residential care facilities	−5,366	−765	−487	−272
Social assistance	−19,307	−2,273	−1,373	−780
Performing arts and spectator sports	−14,706	−52	58	−90
Museums, historical sites, zoos, and parks	−905	16	6	−9
Amusement, gambling, and recreation	−12,535	−117	0	−97
Accommodation	−10,226	−535	−207	−236
Food services and drinking places	−59,287	−3,994	−1,571	−437
Repair and maintenance	−6,893	96	125	−114
Personal and laundry services	−9,940	−59	9	−193
Membership associations and organizations	−6,272	−652	−121	−198
Private households	−5,613	−6	−26	−28
Government	−19,501	−17,469	−2,866	−534
Farm	−199	0	0	0

Appendix 6

Table 6.1. Consumer commodities and services that would account for one-quarter of spending and reinvestment into the San Francisco Bay region, California, economy in the HayWired scenario.

Commodities	
New motor vehicles	Furniture and furnishings
Net purchases of used motor vehicles	Household appliances
Motor vehicle parts and accessories	Household supplies
Motor vehicle fuels, lubricants, and fluids	Glassware, tableware, and household utensils
Motor vehicle maintenance and repair	Men’s and boy’s clothing
Other motor vehicle services	Women’s and girl’s clothing
Fuel oil and other fuels	Children’s and infants’ clothing
Ground transportation	Other clothing materials and footwear
Tools and equipment for house and garden	Personal care products
Musical instruments	Physician services
Books, educational and recreational	Dental services
Telephone and facsimile equipment	Paramedical services
Video, audio, photographic, and information processing equipment and media	Hospitals
Audio-video, photographic, and information processing equipment	Pharmaceutical and other medical products