Decarbonization Project Assignment, Part 1

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Due Oct. 30, 2017

```
library (pacman)
p_load_gh ("gilligan-ees-3310/kayatool")
```

Introduction

In this paper, we will examine the Kaya variable trends over time for United States, China and then the world as a whole. Then, we will examine the decarbonization rates necessary to reach the emissions reduction target set for each country and the world. This paper will conclude with a discussion of the implications drawn from the results of these models.

Data and Plots

First, Let's look at the kaya variable data tables and plot trends for the United States.

```
united_states_P = 0.323
united_states_g = 52.2
united_states_e = 5.35
united_states_f = 59.3
united_states_ef = 317
united_states_G =16.9
united_states_E = 90.2
united_states_F = 5350

united_states_values = tibble(variable = c("P", "g", "e", "f"),
               united_states_value = c(united_states_P, united_states_g, united_st
ates_e, united_states_f))

kable (united_states_values)
```

variable	united_states_value
P	0.323
g	52.200
e	5.350
f	59.300

```
united_states_rate_P = 0.0103
united_states_rate_g = 0.0173
united_states_rate_e = -0.0185
united_states_rate_f = -0.0032
united_states_rate_ef = -.0217
united_states_rate_G =.0276
united_states_rate_E = .0091
united_states_rate_F = .0059

united_states_rates = tibble(variable = c("P", "g", "e", "f"),
               united_states_rate = c(united_states_rate_P, united_states_rate_g,
united_states_rate_e, united_states_rate_f))

kable (united_states_rates)
```

variable	united_states_rate
P	0.0103
g	0.0173
e	-0.0185
f	-0.0032

```
united_states_P_2050 = (united_states_P * exp(united_states_rate_P*(2050-2016)))
united_states_g_2050 = (united_states_g * exp (united_states_rate_g*(2050-2016)))

united_states_f_2050 = (united_states_f * exp (united_states_rate_f * (2050-2016)))
united_states_ef_2050 = (united_states_ef * exp (united_states_rate_ef * (2050-2016
)))
united_states_F_2050 = (united_states_F * exp (united_states_rate_F * (2050-2016)))
united_states_e_2050 = (united_states_e*(exp (united_states_rate_e * (2050-2016))))



united_states_e_2050
```

```
## [1] 2.852217
```

```
united_states_ef_2050
```

```
## [1] 151.5782
```

```
united_states_e_2050
```

```
## [1] 2.852217
```

```
united_states_f_2050
```

```
## [1] 53.18675
```

```
united_states_g_2050
```

```
## [1] 93.99884
```

```
united_states_P_2050
```

```
## [1] 0.4584505
```

```
united_states_2050_values = tibble(variable = c("P", "g", "e", "f"),
               united_states_2050_value = c(united_states_P_2050, united_states_g_
2050, united_states_e_2050, united_states_f_2050))

kable (united_states_2050_values)
```

variable	united_states_2050_value
P	0.4584505
g	93.9988450
e	2.8522169
f	53.1867500

```
united_states_F_2005 = 5350
```

```
united_states_F_target = united_states_F *(1-.73)
united_states_F_target
```

```
## [1] 1444.5
```

```
united_states_implied_rate_F = log(united_states_F_2050/ united_states_F_2005) / (2
050 - 2005)

united_states_implied_rate_F
```

```
## [1] 0.004457778
```

```
united_states_implied_rate_F = log(united_states_F_2050/ united_states_F_2005) / (2
050 - 2005)

united_states_implied_rate_F
```

```
## [1] 0.004457778
```

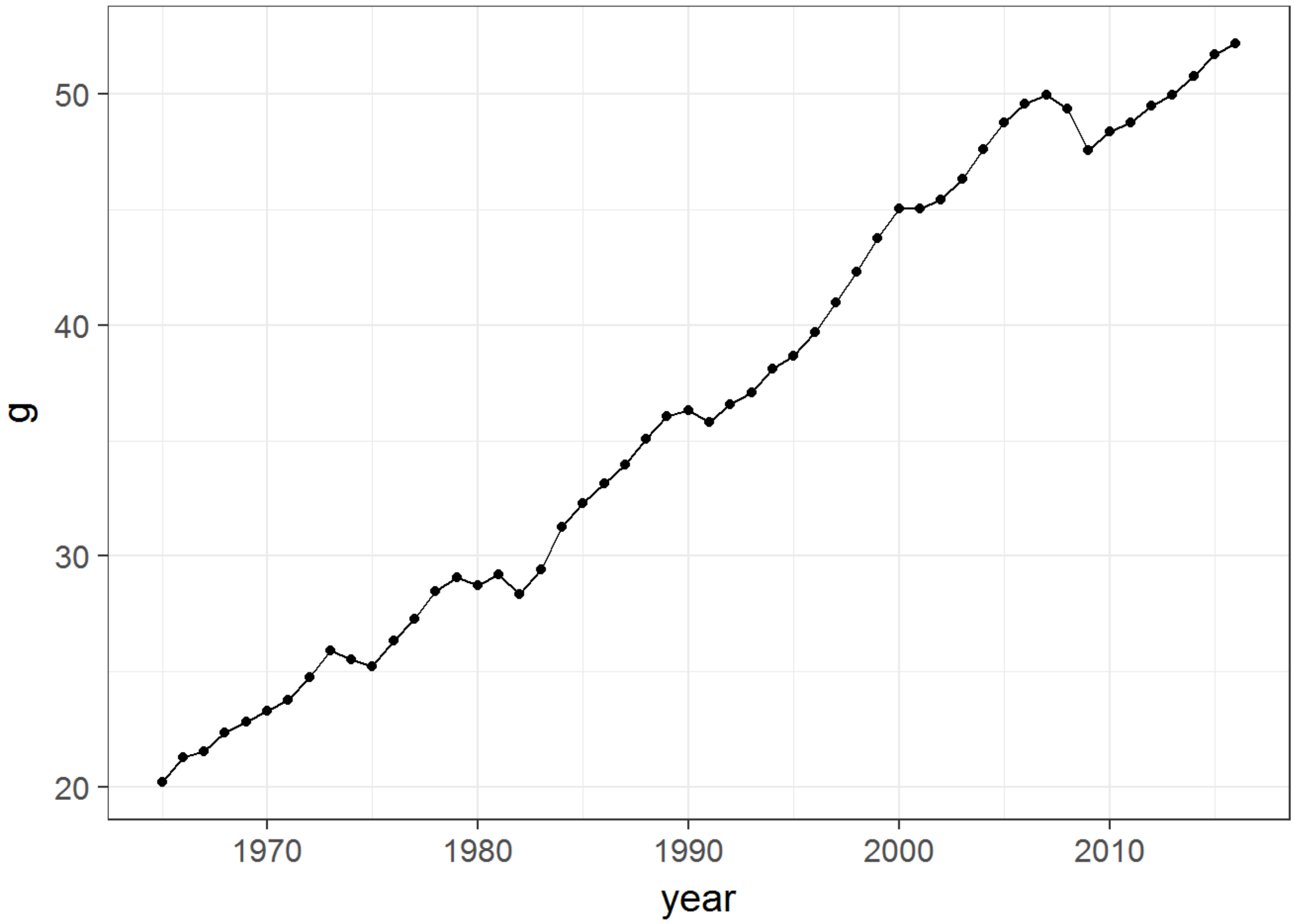
```r
united_states_decarbonization_rate = united_states_implied_rate_F -united_states_ra
te_P - united_states_rate_g

united_states_decarbonization_rate
```

```
## [1] -0.02314222
```

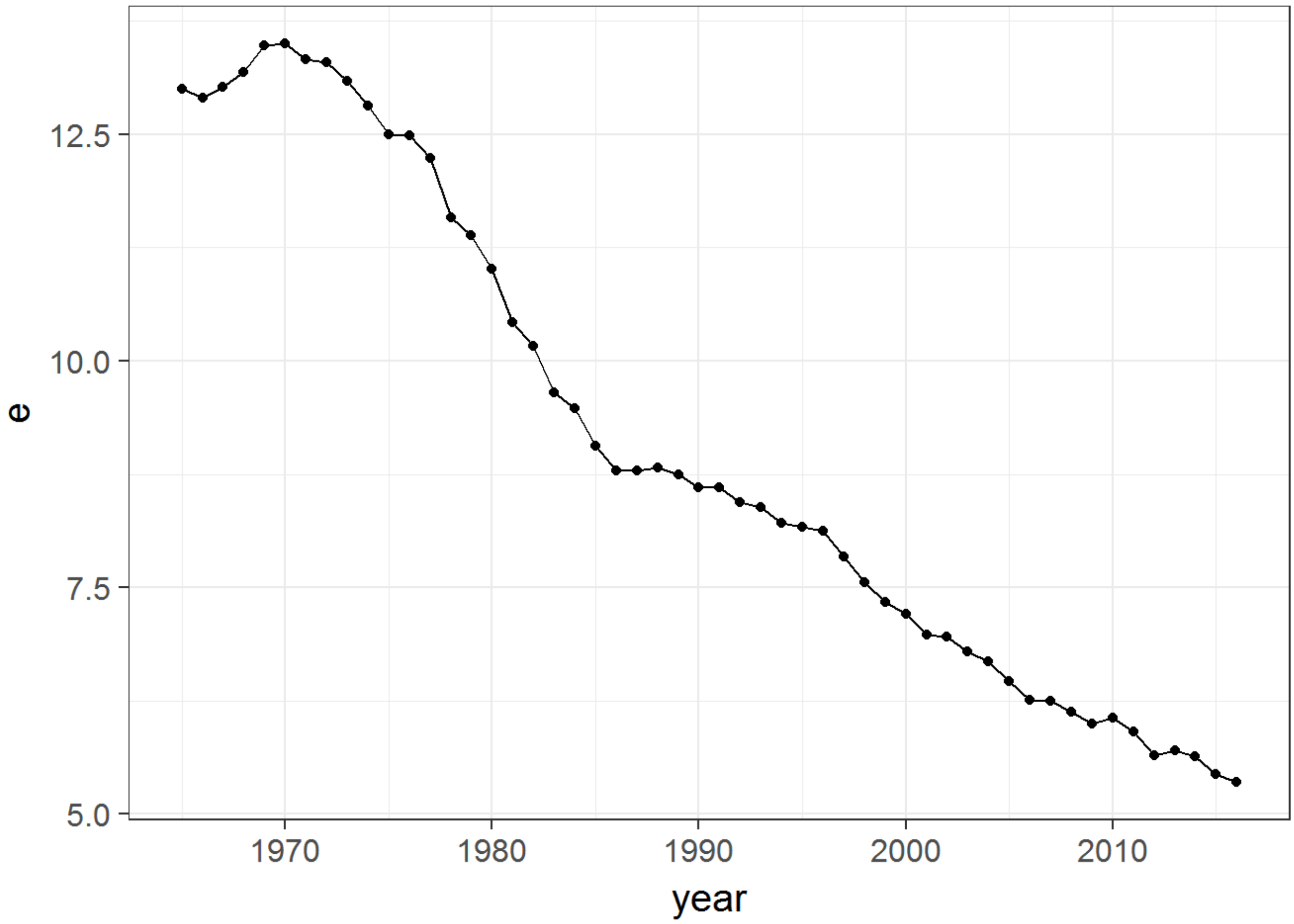
```r
united_states_data = read_csv('United_States.csv')
```

```
## Parsed with column specification:
## cols(
##   country_code = col_character(),
##   year = col_integer(),
##   P = col_double(),
##   G = col_double(),
##   g = col_double(),
##   E = col_double(),
##   F = col_double(),
##   e = col_double(),
##   f = col_double(),
##   ef = col_double()
## )
```

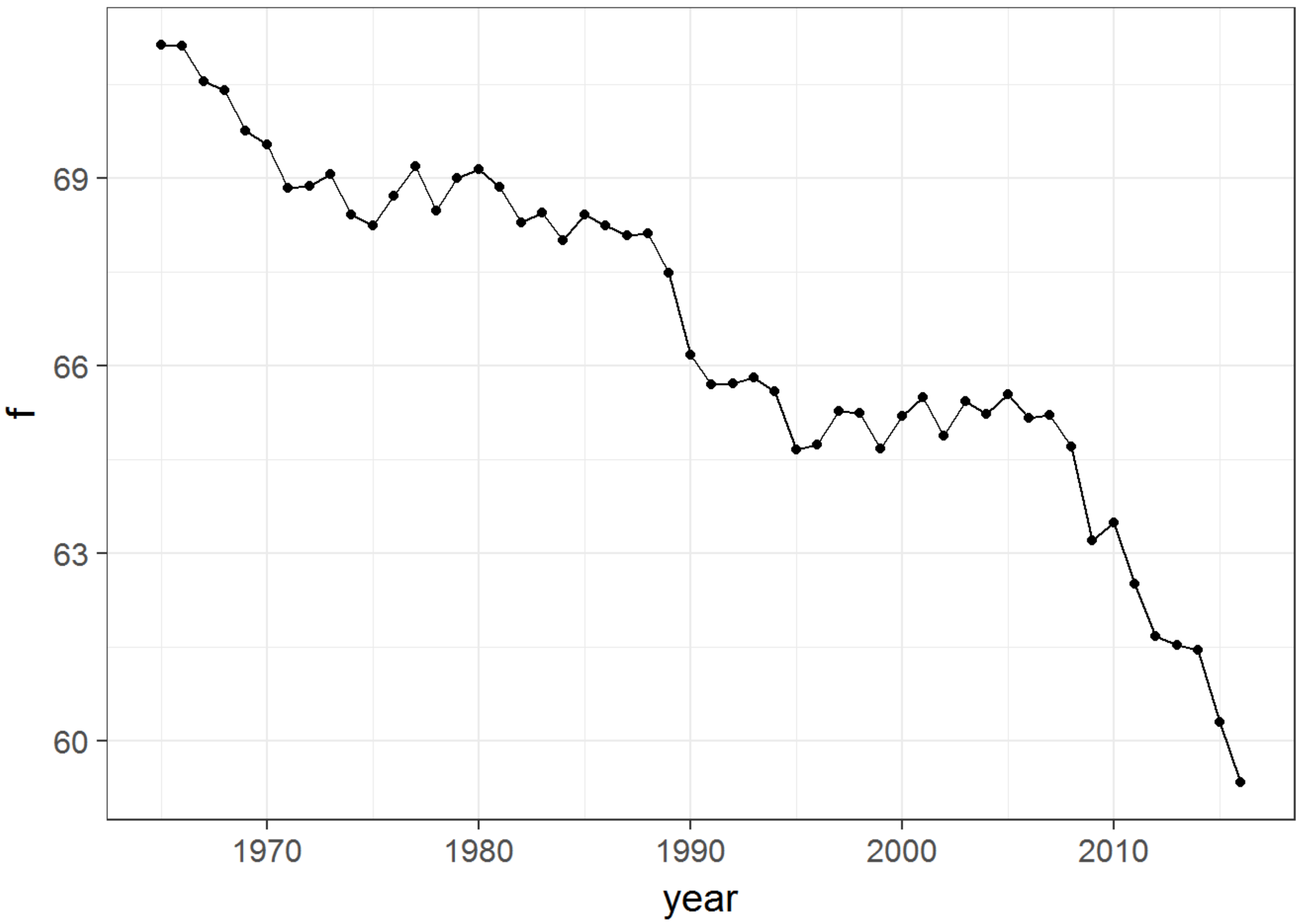
```r
ggplot(united_states_data, aes(x = year, y= g)) +
  geom_line() + geom_point()
```



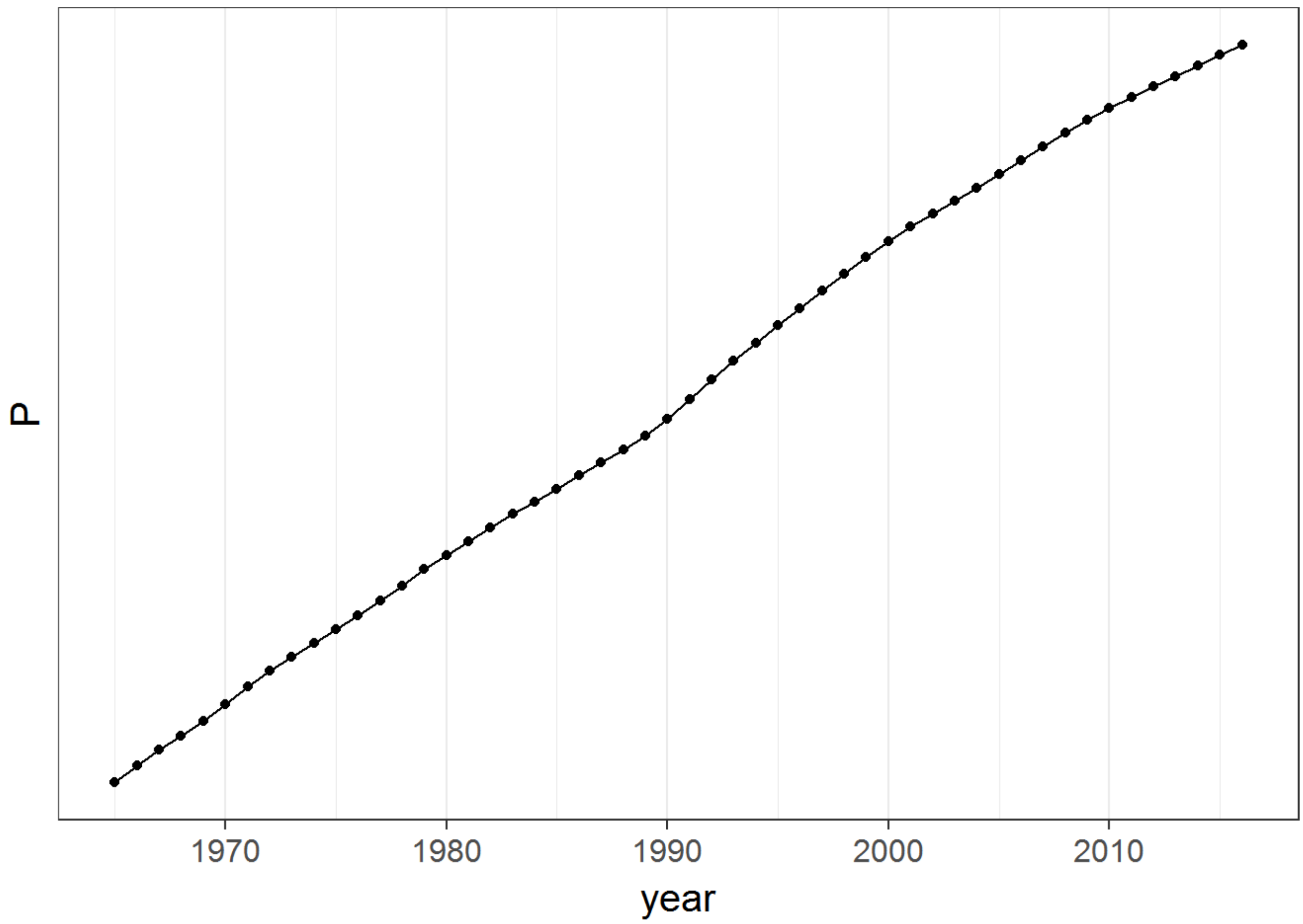
```
ggplot(united_states_data, aes(x = year, y= e)) +
  geom_line() + geom_point()
```



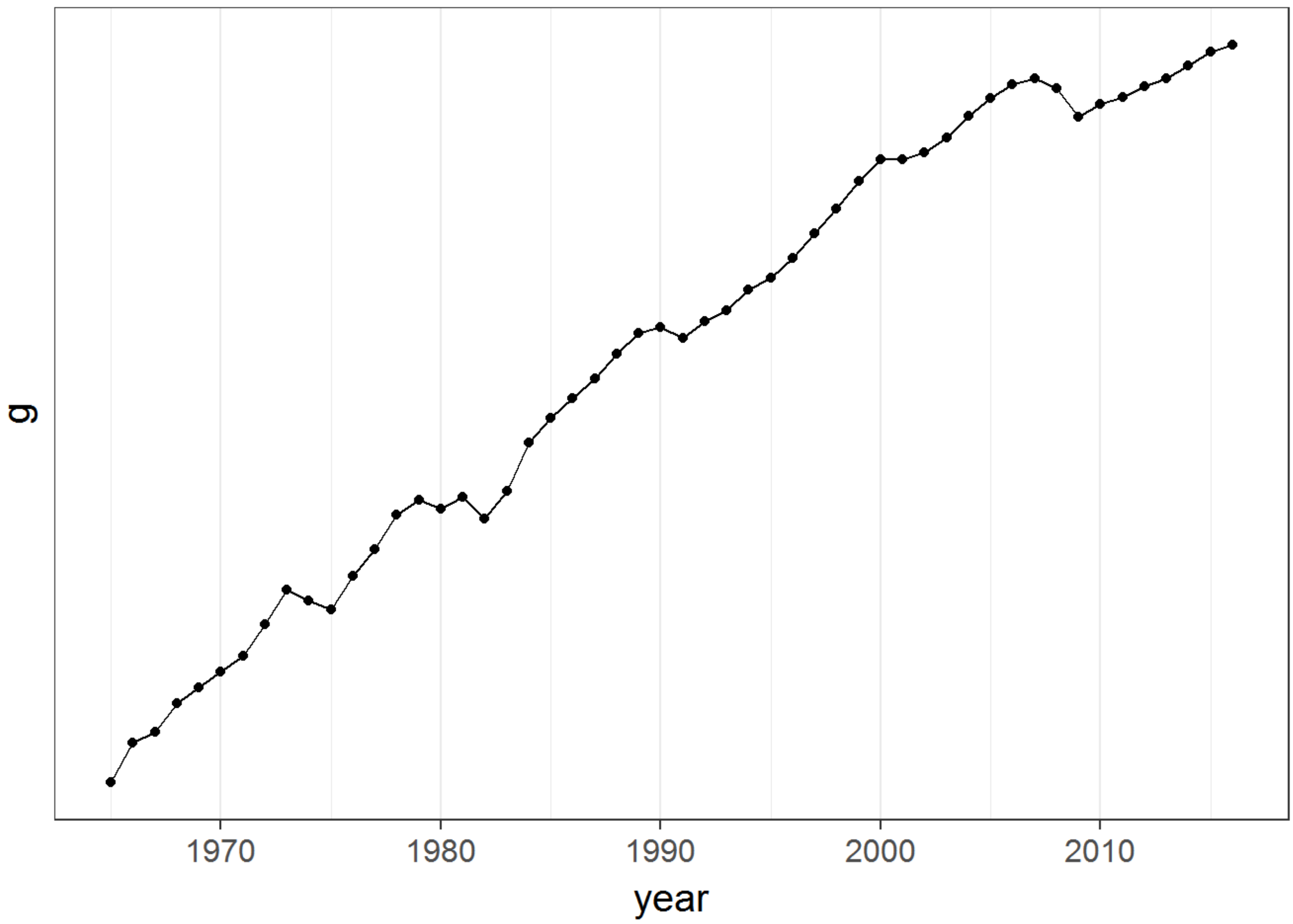

```
ggplot(united_states_data, aes(x = year, y= f)) +
  geom_line() + geom_point()
```



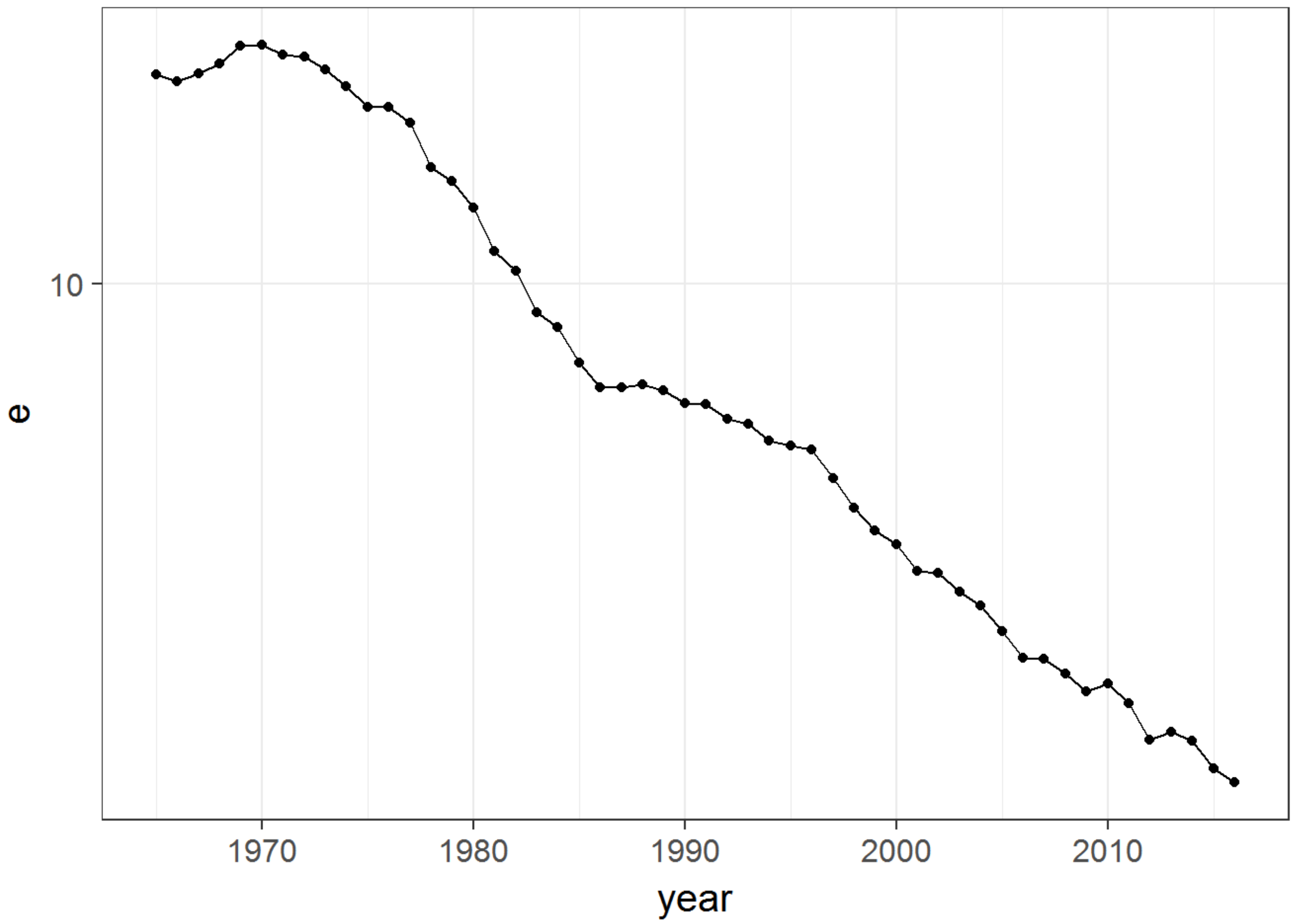

```
ggplot(united_states_data, aes(x = year, y= P)) +
  geom_line() + geom_point() +
  scale_y_log10()
```



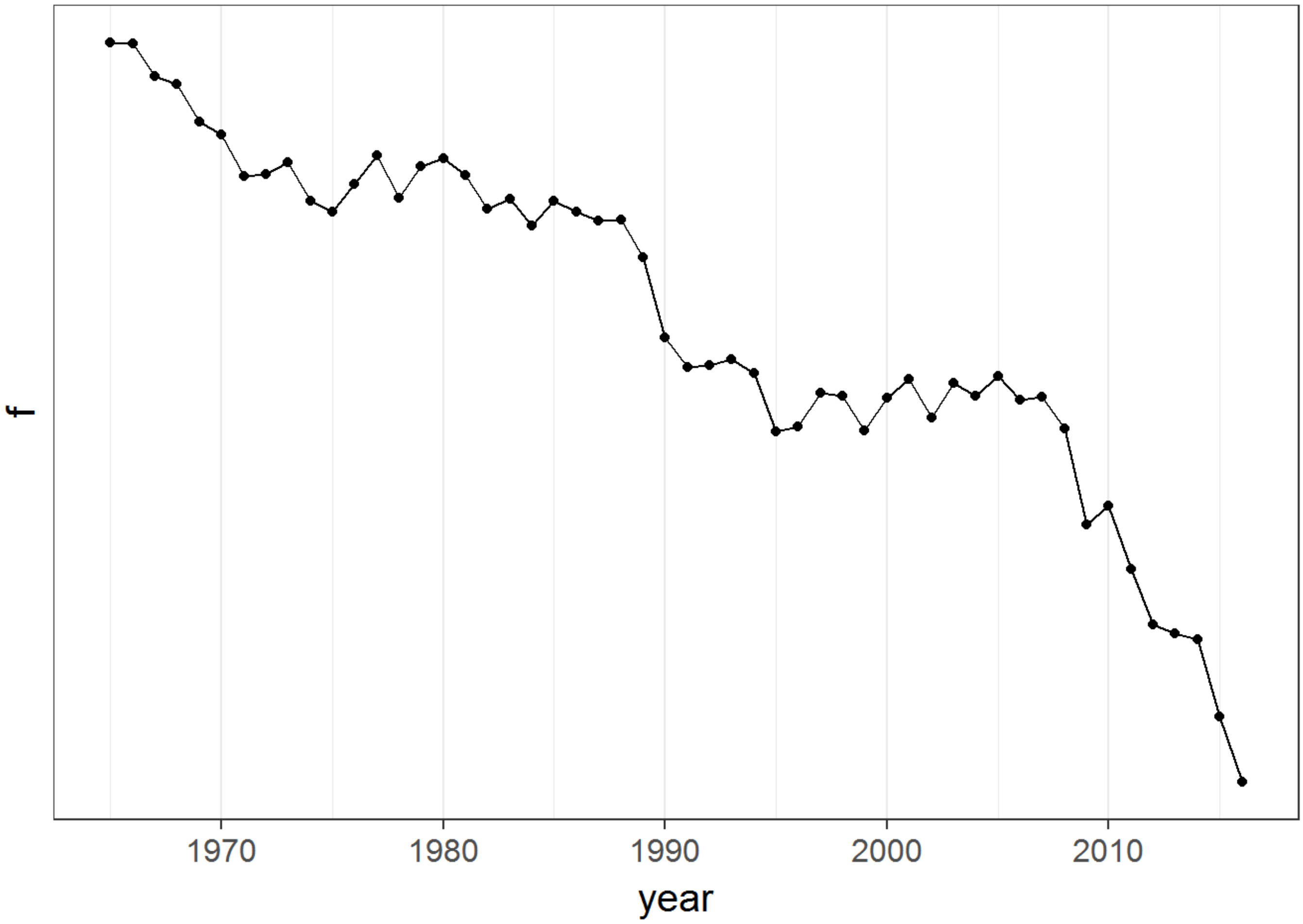

```
ggplot(united_states_data, aes(x = year, y= g)) +
  geom_line() + geom_point() +
  scale_y_log10()
```




```
ggplot(united_states_data, aes(x = year, y= e)) +
  geom_line() + geom_point() +
  scale_y_log10()
```




```
ggplot(united_states_data, aes(x = year, y= f)) +
  geom_line() + geom_point() +
  scale_y_log10()
```




```
# average annual growth rate of per-capita GDP, in percent per year
P_fit = lm(log(P)~ year, data = united_states_data)
rate_P = summary(P_fit)$coefficients['year', 'Estimate']

g_fit = lm(log(g)~ year, data = united_states_data)
rate_g = summary(g_fit)$coefficients['year', 'Estimate']

e_fit = lm(log(e)~ year, data = united_states_data)
rate_e = summary(e_fit)$coefficients['year', 'Estimate']
```

Now, Let's look at the kaya variable trends for China.

```
china_P = 1.378665
china__G =9.505156725
china_g = 6.894464373
china_E = 121.1501325
china_F = 9123.049428
china_e = 12.74572698
china_f = 75.30366858
china_ef = 959.8000004

china_values = tibble(variable = c("P", "g", "e", "f"),
               china_value = c(china_P, china_g, china_e, china_f))

kable (china_values)
```

variable	china_value

variable	china_value
P	1.378665
g	6.894464
e	12.745727
f	75.303669

```
china_rate_P = 0.0094
china_rate_g = 0.0854
china_rate_e = -0.0347
china_rate_f = -0.0032
china_rate_ef = -0.0379
china_rate_G =0.0948
china_rate_E = 0.0601
china_rate_F = 0.0569

china_rates = tibble(variable = c("P", "g", "e", "f"),
               china_rate = c(china_rate_P, china_rate_g, china_rate_e, china_rate
_f))

kable (china_rates)
```

variable	china_rate
P	0.0094
g	0.0854
e	-0.0347
f	-0.0032

```
china_P_2050 = china_P * exp(china_P*(2050-2016))
china_g_2050 = (china_g * exp (china_rate_g*(2050-2016)))

china_f_2050 = (china_f * exp (china_rate_f * (2050-2016)))
china_ef_2050 = (china_ef * exp (china_rate_ef * (2050-2016)))
china_F_2050 = (china_F * exp (china_rate_F * (2050-2016)))
china_e_2050 = (china_e*(exp (china_rate_e * (2050-2016))))



china_e_2050
```

```
## [1] 3.917274
```

```
china_ef_2050
```

```
## [1] 264.575
```

```
china_e_2050
```

```
## [1] 3.917274
```

```
china_f_2050
```

```
## [1] 67.5406
```

```
china_g_2050
```

```
## [1] 125.7529
```

```
china_P_2050
```

```
## [1] 3.139375e+20
```

```
china_2050_values = tibble(variable = c("P", "g", "e", "f"),
                china_2050_value = c(china_P_2050, china_g_2050, china_e_2050, chin
a_f_2050))

kable (china_2050_values)
```

variable	china_2050_value
P	3.139375e+20
g	1.257529e+02
e	3.917274e+00
f	6.754060e+01

```
china_F_target = china_F *(1-.78)

china_F_target
```

```
## [1] 2007.071
```

```
china_F_2005 = 9123
```

```
china_implied_rate_F = log(china_F_2050/ china_F_2005) / (2050 - 2005)

china_implied_rate_F = -china_implied_rate_F

china_implied_rate_F
```

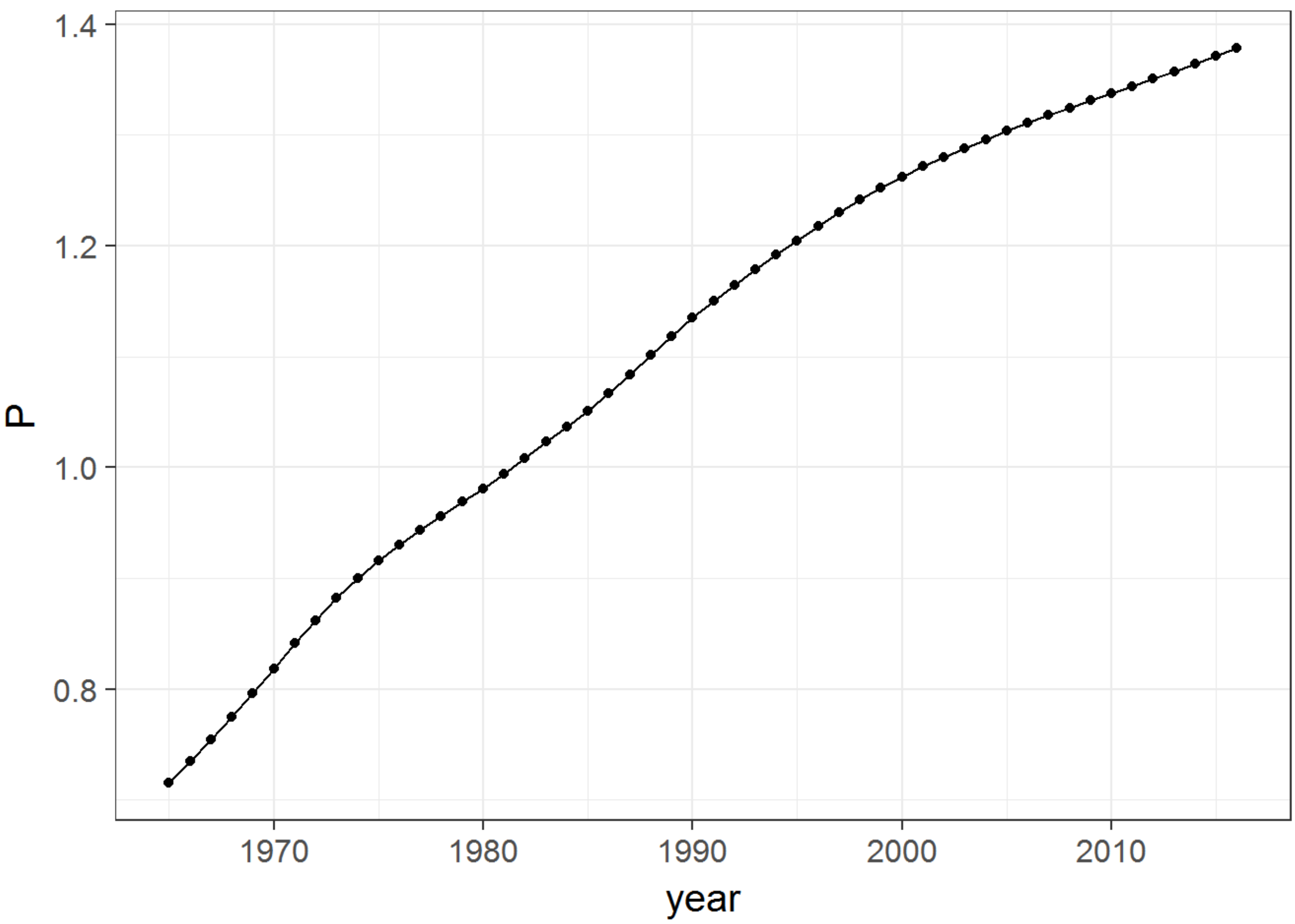
```
## [1] -0.04299123
```

```
china_decarbonization_rate = china_implied_rate_F -china_rate_P - china_rate_g
```

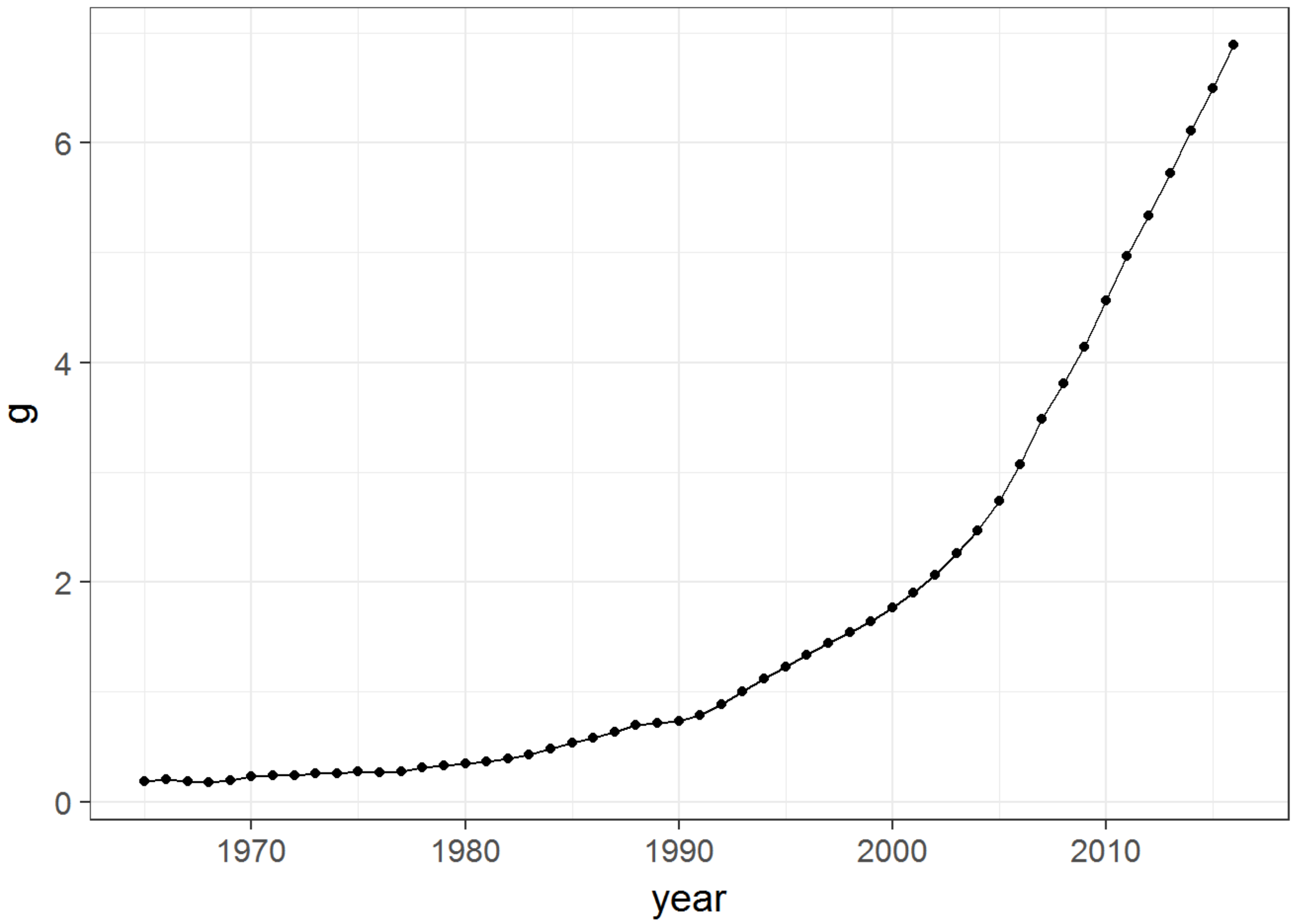
```r
china_data = read_csv('China.csv')
```

```
## Parsed with column specification:
## cols(
##   country_code = col_character(),
##   year = col_integer(),
##   P = col_double(),
##   G = col_double(),
##   g = col_double(),
##   E = col_double(),
##   F = col_double(),
##   e = col_double(),
##   f = col_double(),
##   ef = col_double()
## )
```

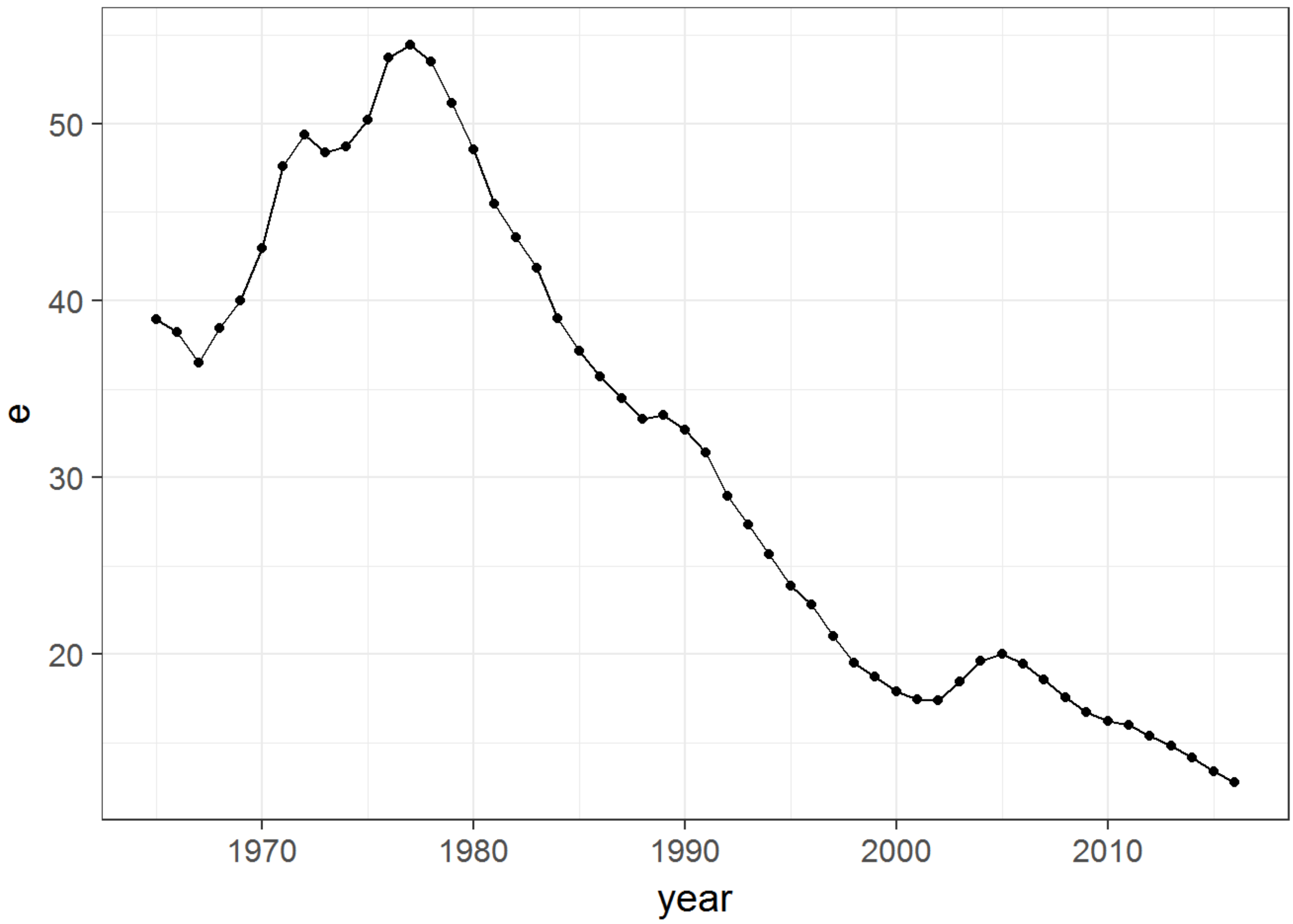
```r
ggplot(china_data, aes(x = year, y= P)) +
  geom_line() + geom_point()
```



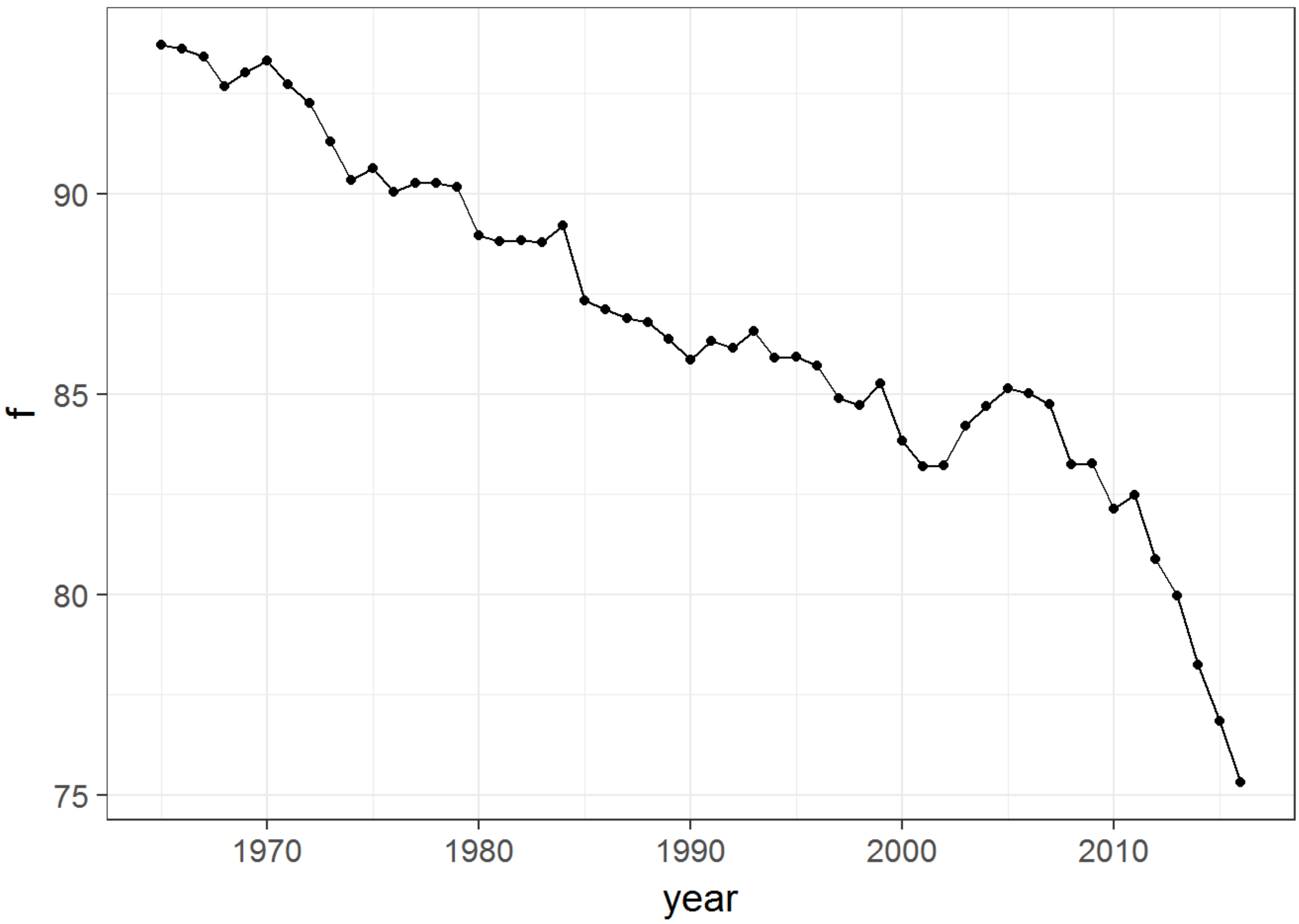

```r
ggplot(china_data, aes(x = year, y= g)) +
  geom_line() + geom_point()
```



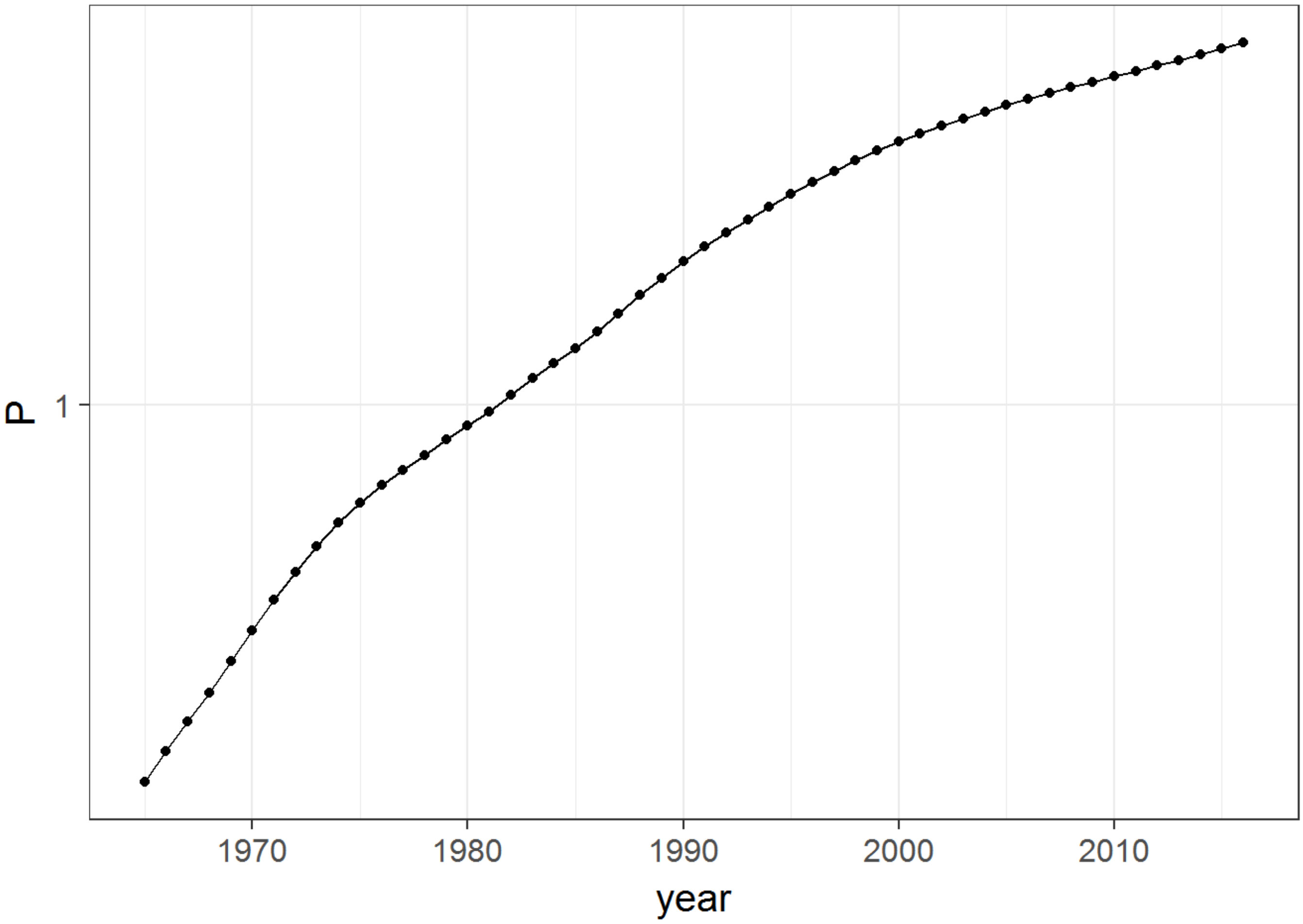

```
ggplot(china_data, aes(x = year, y= e)) +
  geom_line() + geom_point()
```



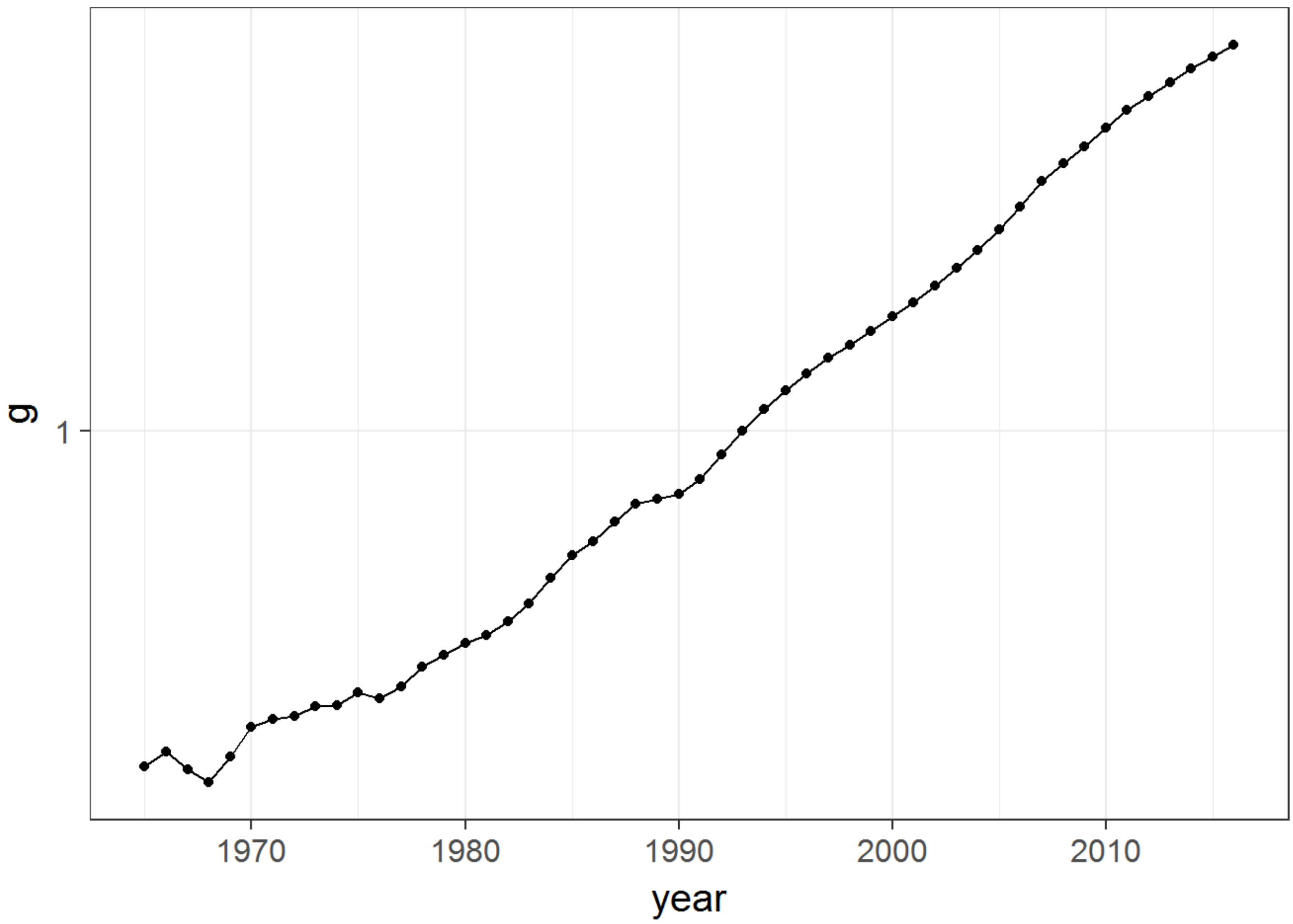

```
ggplot(china_data, aes(x = year, y= f)) +
  geom_line() + geom_point()
```



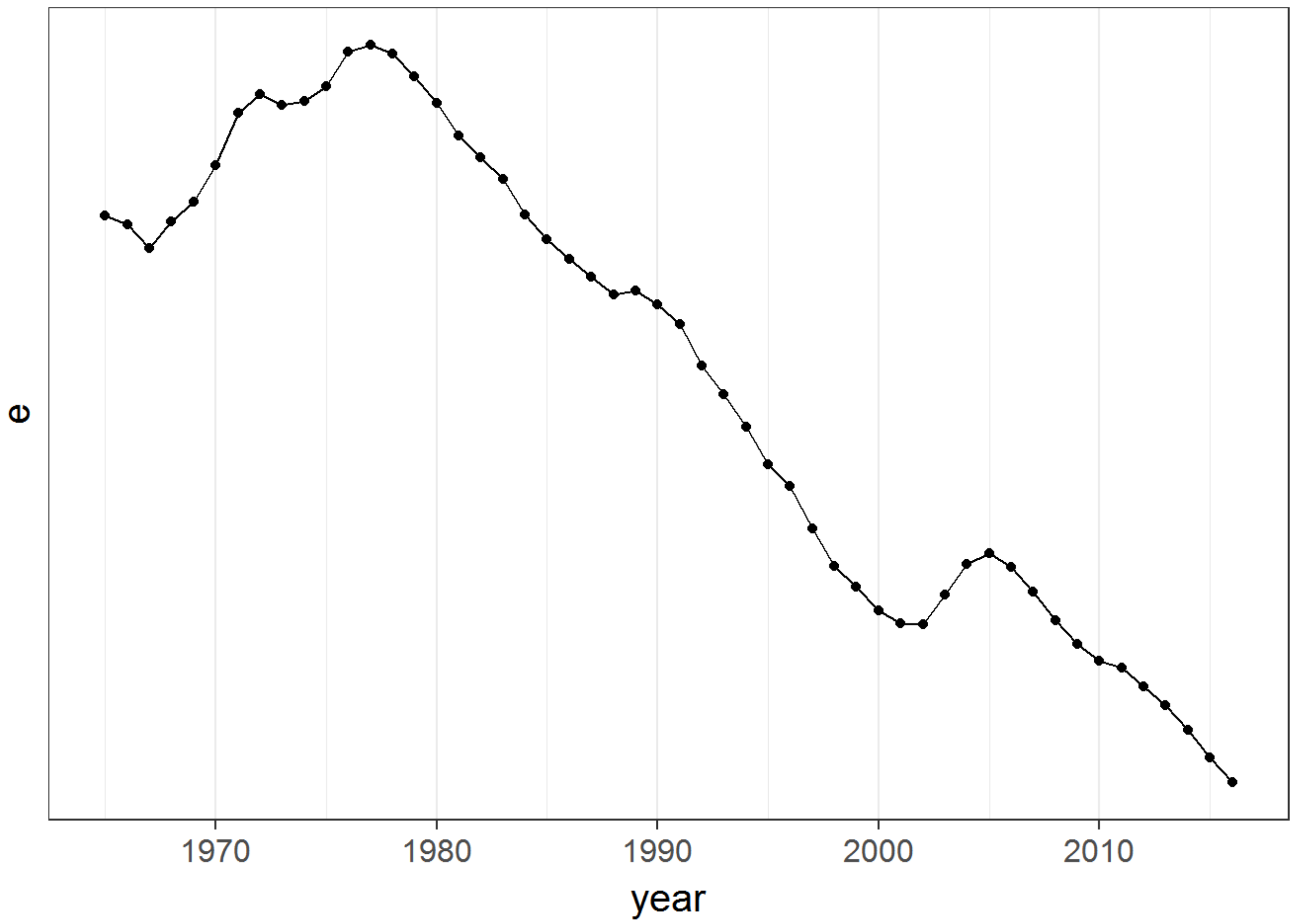

```
ggplot(china_data, aes(x = year, y= P)) +
  geom_line() + geom_point() +
  scale_y_log10()
```



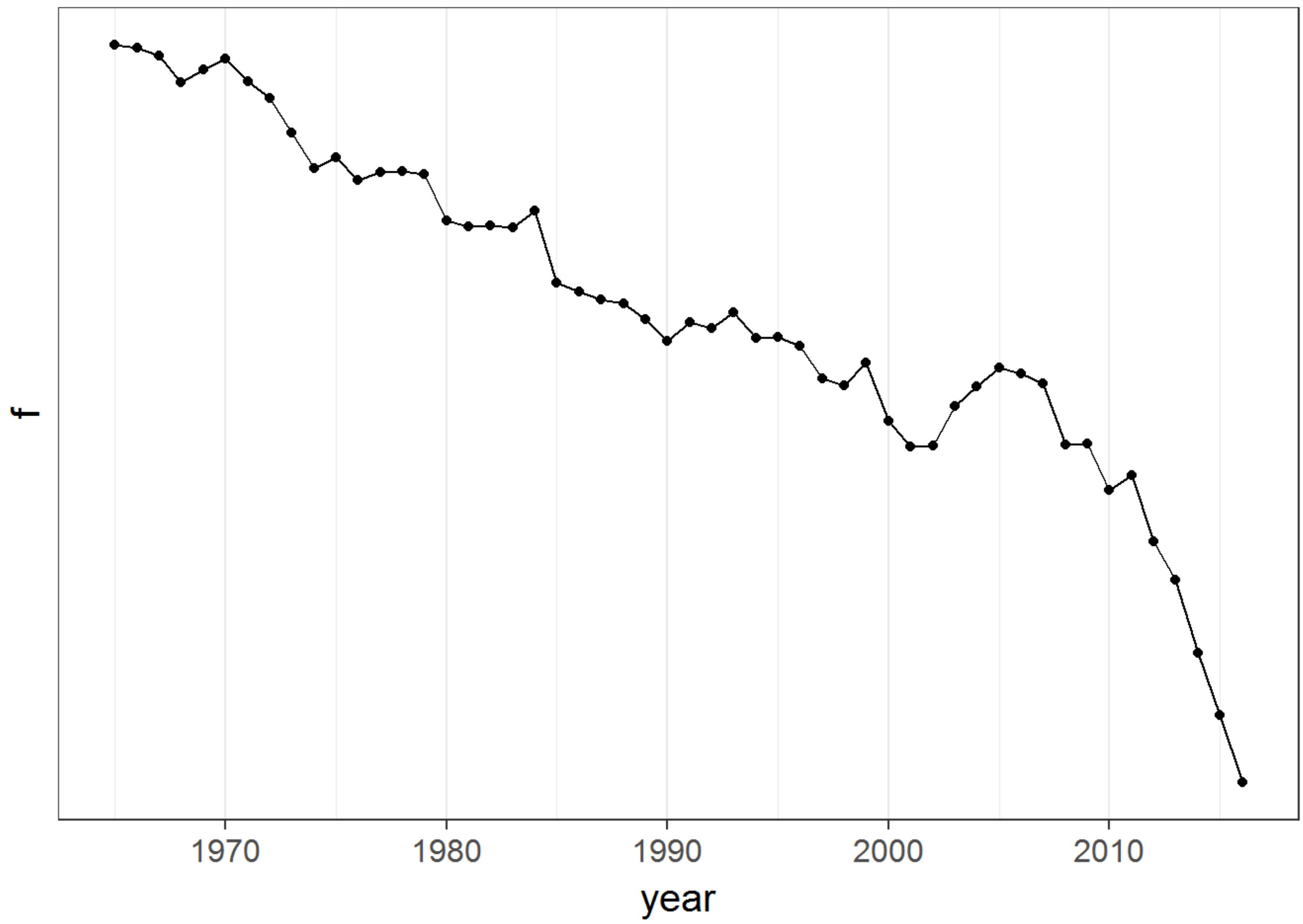

```
ggplot(china_data, aes(x = year, y= g)) +
  geom_line() + geom_point() +
  scale_y_log10()
```




```
ggplot(china_data, aes(x = year, y= e)) +
  geom_line() + geom_point() +
  scale_y_log10()
```




```
ggplot(china_data, aes(x = year, y= f)) +
  geom_line() + geom_point() +
  scale_y_log10()
```




```
# average annual growth rate of per-capita GDP, in percent per year
P_fit = lm(log(P)~ year, data = china_data)
rate_P = summary(P_fit)$coefficients['year', 'Estimate']

g_fit = lm(log(g)~ year, data = china_data)
rate_g = summary(g_fit)$coefficients['year', 'Estimate']

e_fit = lm(log(e)~ year, data = china_data)
rate_e = summary(e_fit)$coefficients['year', 'Estimate']

f_fit = lm(log(f)~ year, data = china_data)
rate_f = summary(f_fit)$coefficients['year', 'Estimate']

china_rates = tibble(variable = c("P", "g", "e", "f"),
              china_rate = c(china_rate_P, china_rate_g, china_rate_e, china_rate
_f))

kable(china_rates)
```

variable	china_rate
P	0.0094
g	0.0854
e	-0.0347
f	-0.0032

Finally, Let's look at the kaya variable trends for the whole world.

```
 world_P = 7.442136
 world_G = 77.32785
 world_g = 10.39055
 world_E = 526.8376
 world_F = 33432.04
 world_e = 6.813038
 world_f = 63.45797
 world_ef = 432.3416

world_values = tibble(variable = c("P", "g", "e", "f"),
               world_value = c(world_P, world_g, world_e, world_f))

kable(world_values)
```

variable	world_value
P	7.442136
g	10.390550
e	6.813038
f	63.457970

```
world_rate_P = 0.0142
world_rate_g = 0.0151
world_rate_e = -0.0088
world_rate_f = -.0020
world_rate_ef = -0.0108
world_rate_G = 0.0293
world_rate_E = 0.0205
world_rate_F = 0.0185

world_rates = tibble(variable = c("P", "g", "e", "f"),
               world_rate = c(world_rate_P, world_rate_g, world_rate_e, world_rate
_f))
```

```
world_P_2050 = world_P * exp(world_P*(2050-2016))
world_g_2050 = (world_g * exp (world_rate_g*(2050-2016)))

world_f_2050 = (world_f * exp (world_rate_f * (2050-2016)))
world_ef_2050 = (world_ef * exp (world_rate_ef * (2050-2016)))
world_F_2050 = (world_F * exp (world_rate_F * (2050-2016)))
world_e_2050 = (world_e*(exp (world_rate_e * (2050-2016))))

world_2050_values = tibble(variable = c("P", "g", "e", "f"),
               world_2050_values = c(world_P_2050, world_g_2050, world_e_2050, wor
ld_f_2050))

kable (world_2050_values)
```

variable	world_2050_values

variable	world_2050_values
P	5.785887e+110
g	1.736222e+01
e	5.051262e+00
f	5.928627e+01

```
world_F_target = world_F *(1-.36)

world_F_target
```

```
## [1] 21396.51
```

```
world_F_2005 = 33432.04
```

```
world_implied_rate_F = log(world_F_2050/ world_F_2005) / (2050 - 2005)

world_implied_rate_F = -world_implied_rate_F

world_implied_rate_F
```

```
## [1] -0.01397778
```

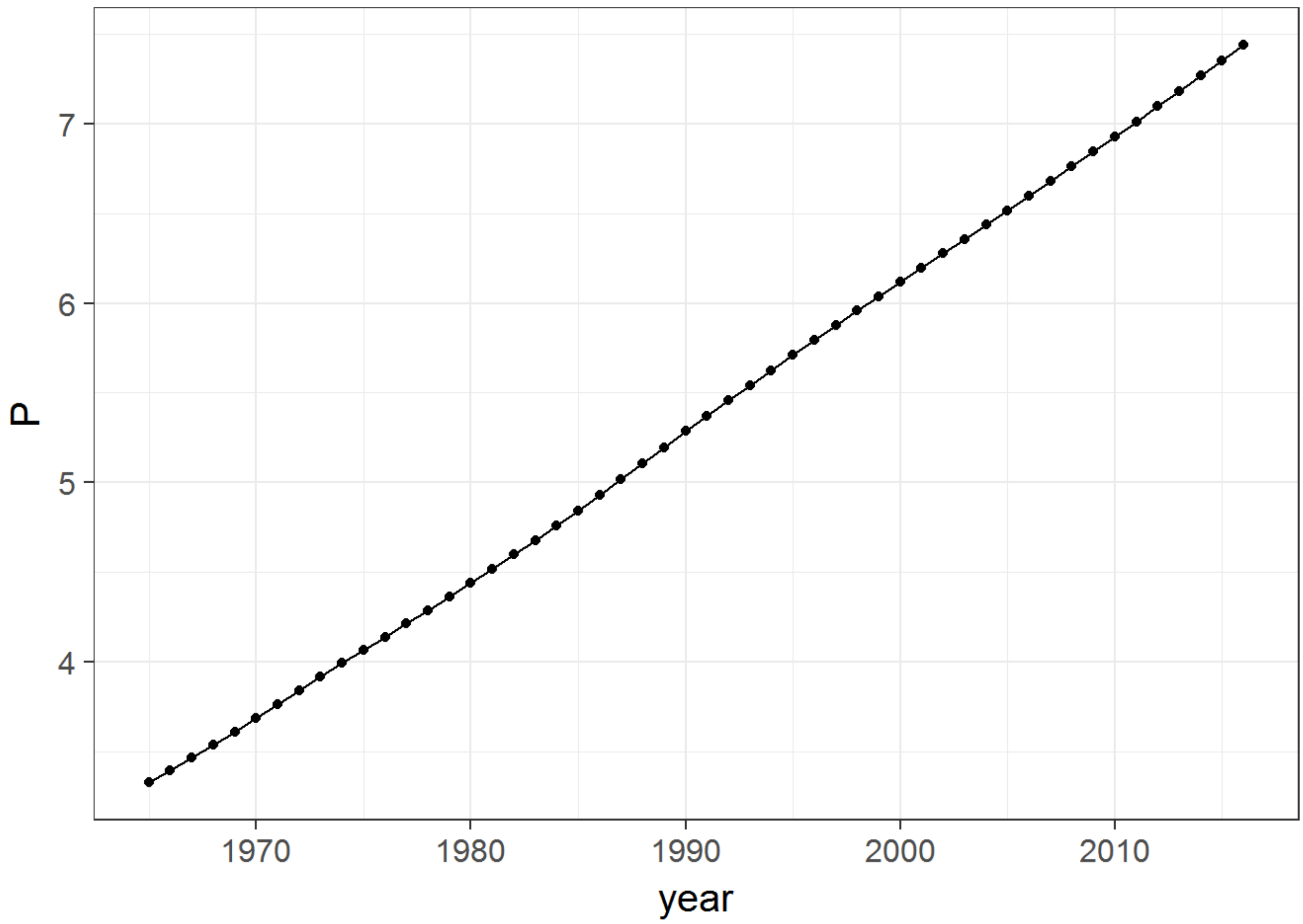
```
world_decarbonization_rate = world_implied_rate_F -world_rate_P - world_rate_g

world_decarbonization_rate
```

```
## [1] -0.04327778
```

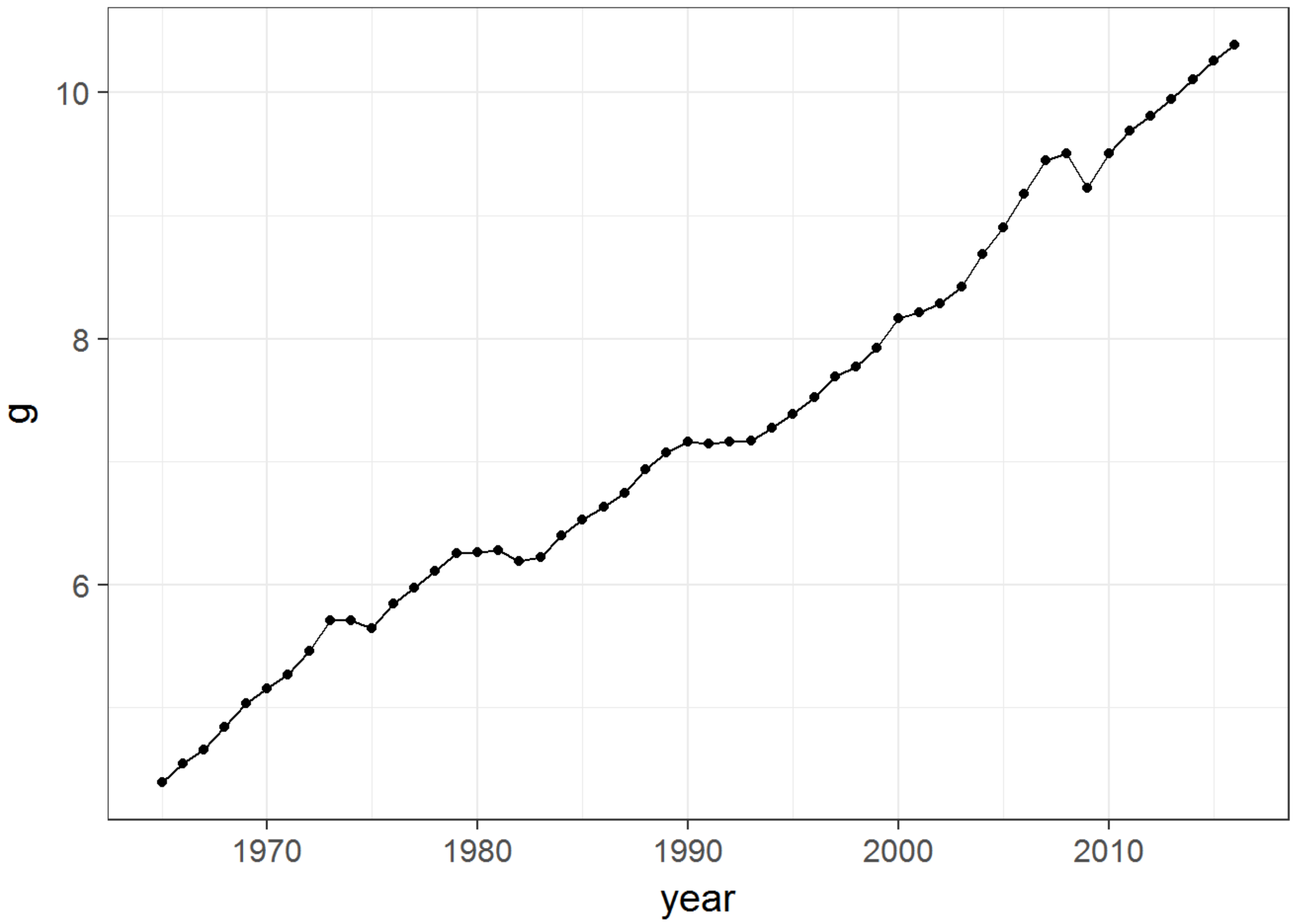
```
world_data = read_csv('World.csv')
```

```
## Parsed with column specification:
## cols(
##   country_code = col_character(),
##   year = col_integer(),
##   P = col_double(),
##   G = col_double(),
##   g = col_double(),
##   E = col_double(),
##   F = col_double(),
##   e = col_double(),
##   f = col_double(),
##   ef = col_double()
## )
```

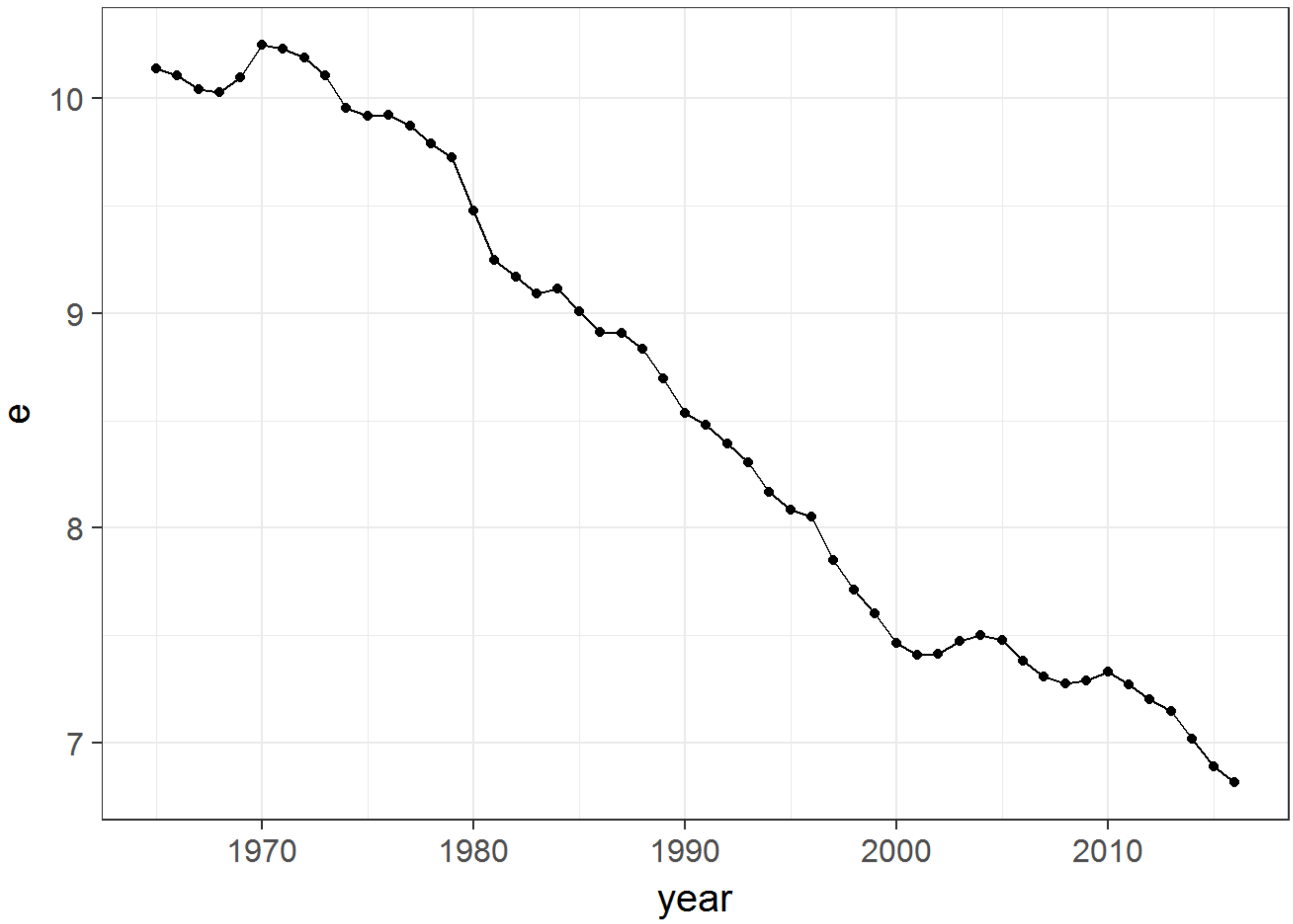
```
ggplot(world_data, aes(x = year, y= P)) +
  geom_line() + geom_point()
```



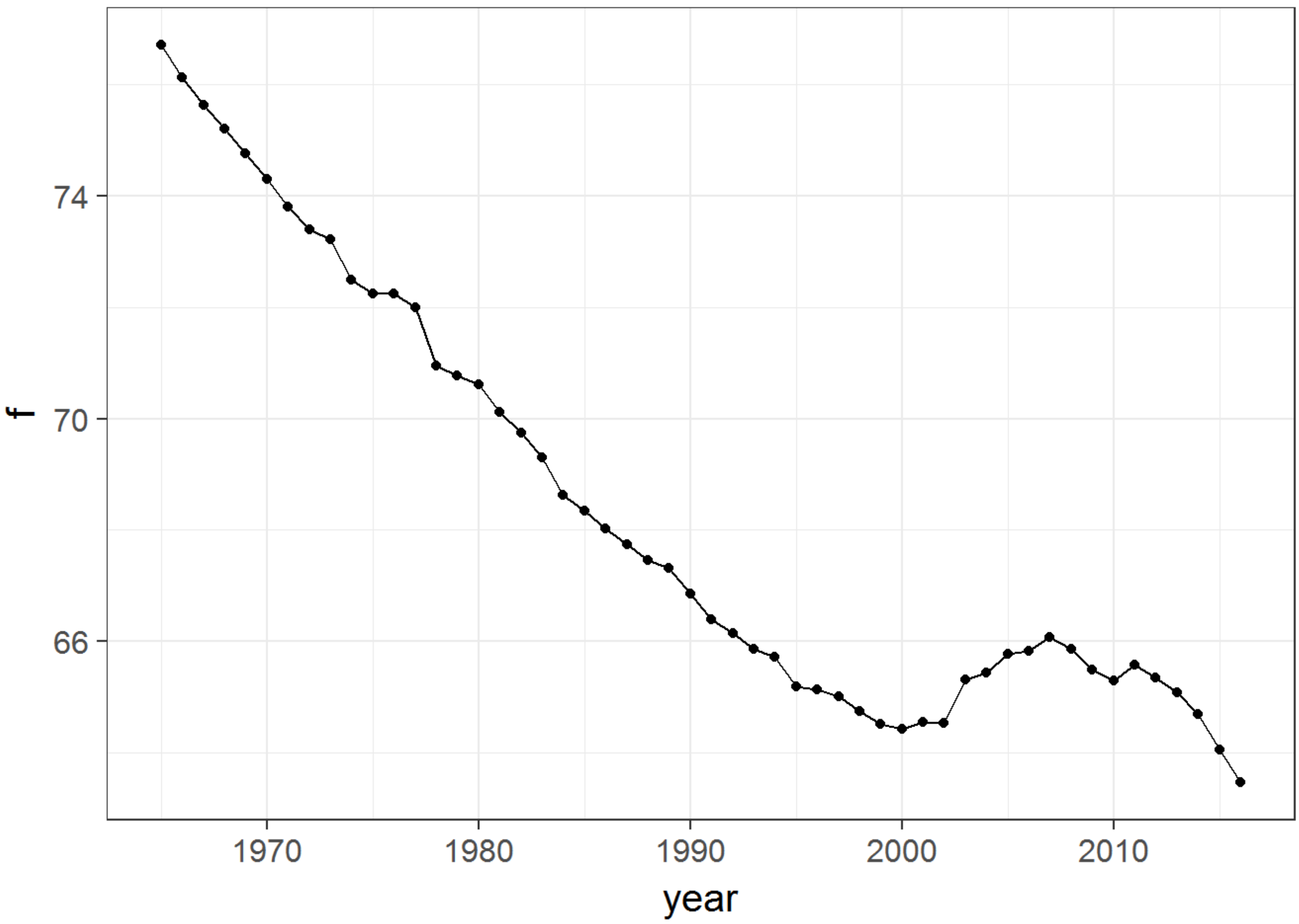

```
ggplot(world_data, aes(x = year, y= g)) +
  geom_line() + geom_point()
```



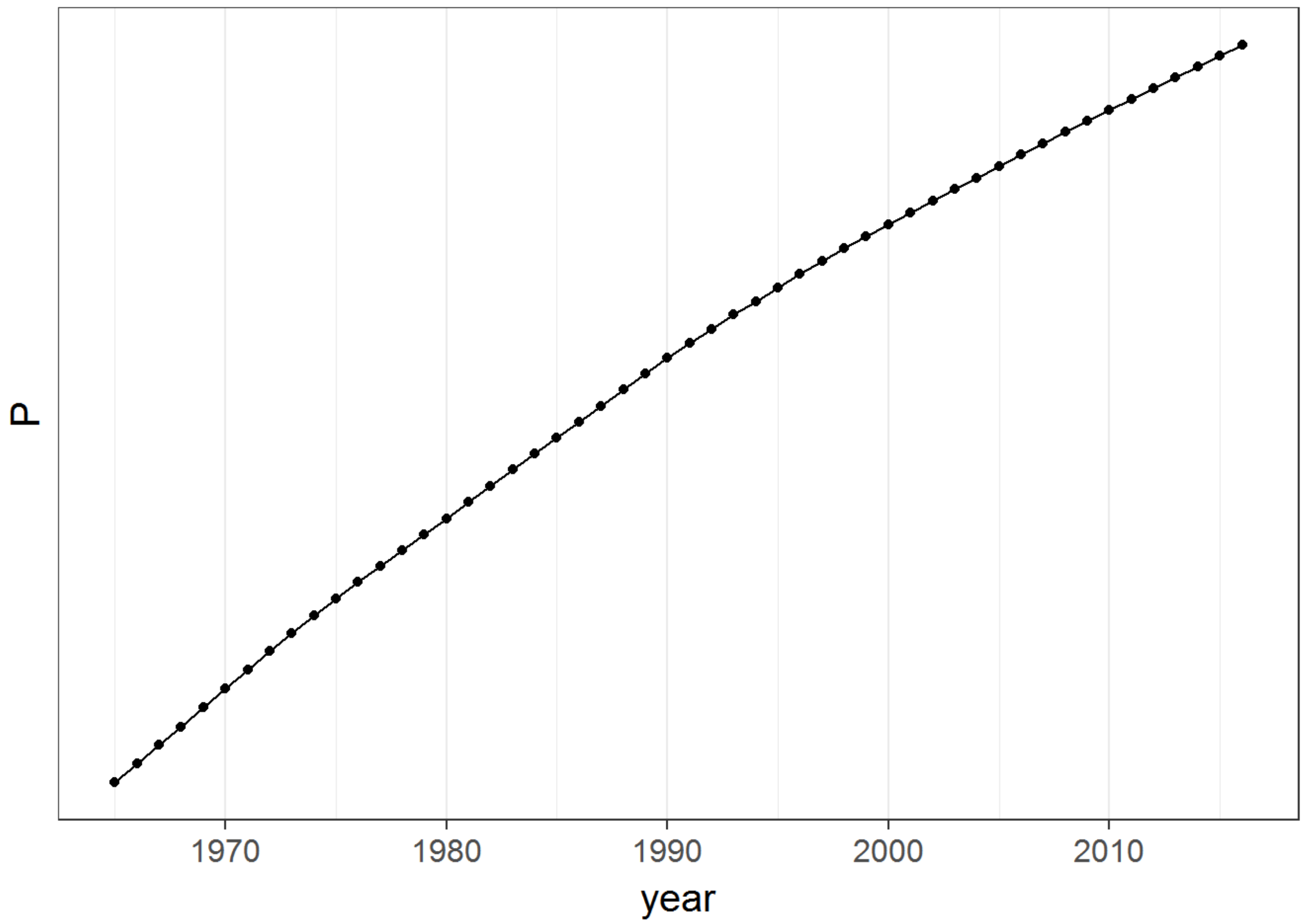

```
ggplot(world_data, aes(x = year, y= e)) +
  geom_line() + geom_point()
```



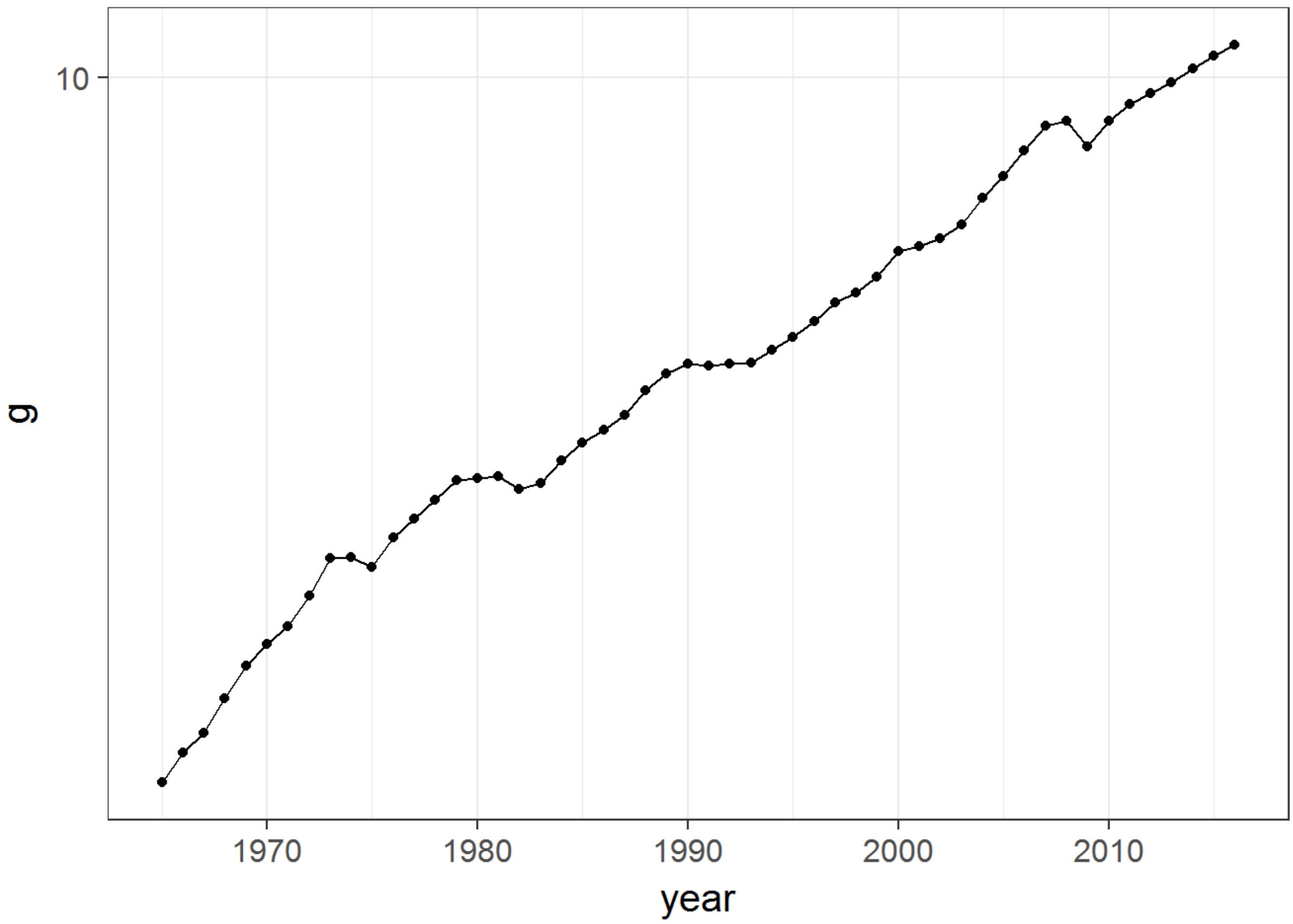

```
ggplot(world_data, aes(x = year, y= f)) +
  geom_line() + geom_point()
```



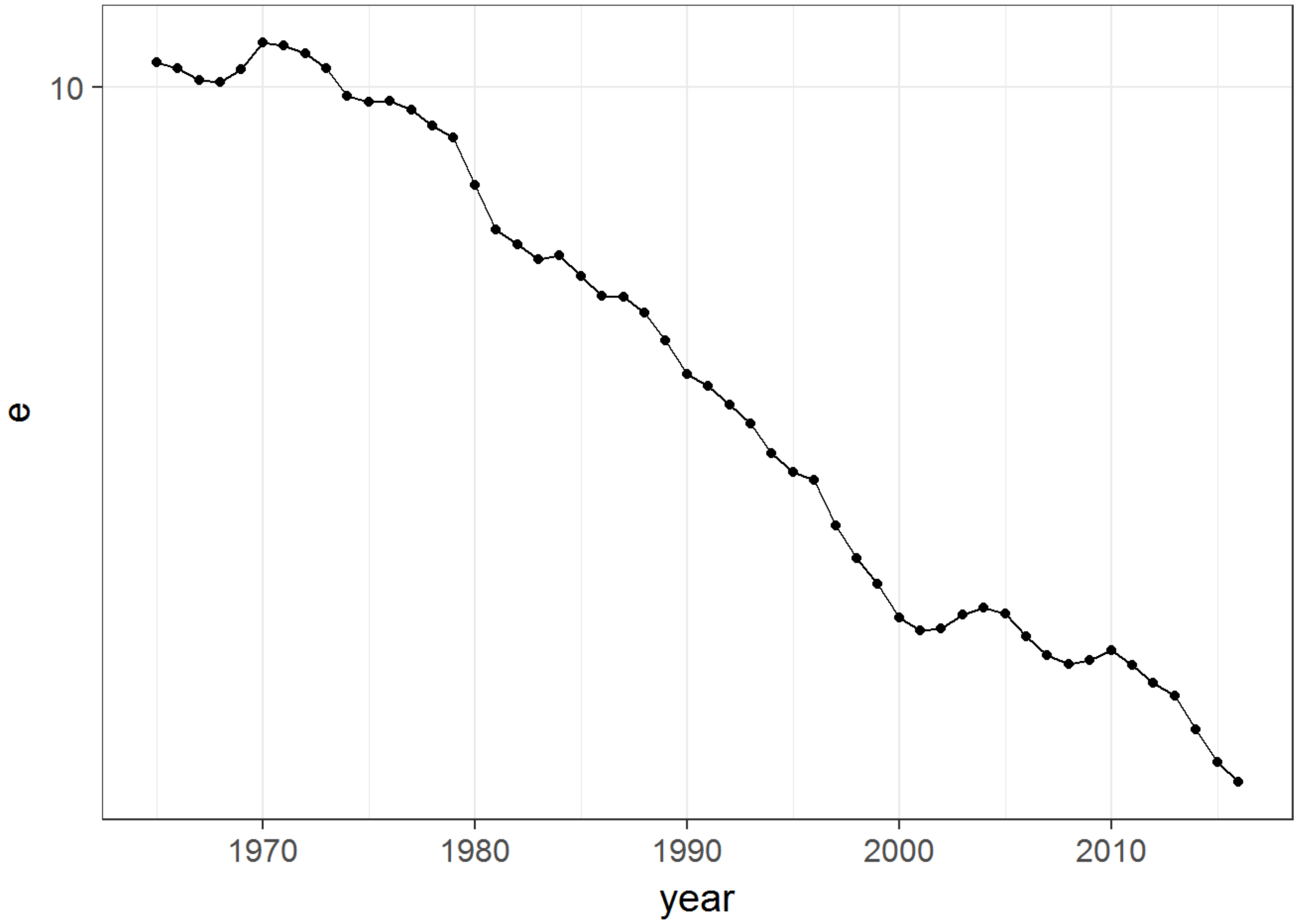

```
ggplot(world_data, aes(x = year, y= P)) +
  geom_line() + geom_point() +
  scale_y_log10()
```



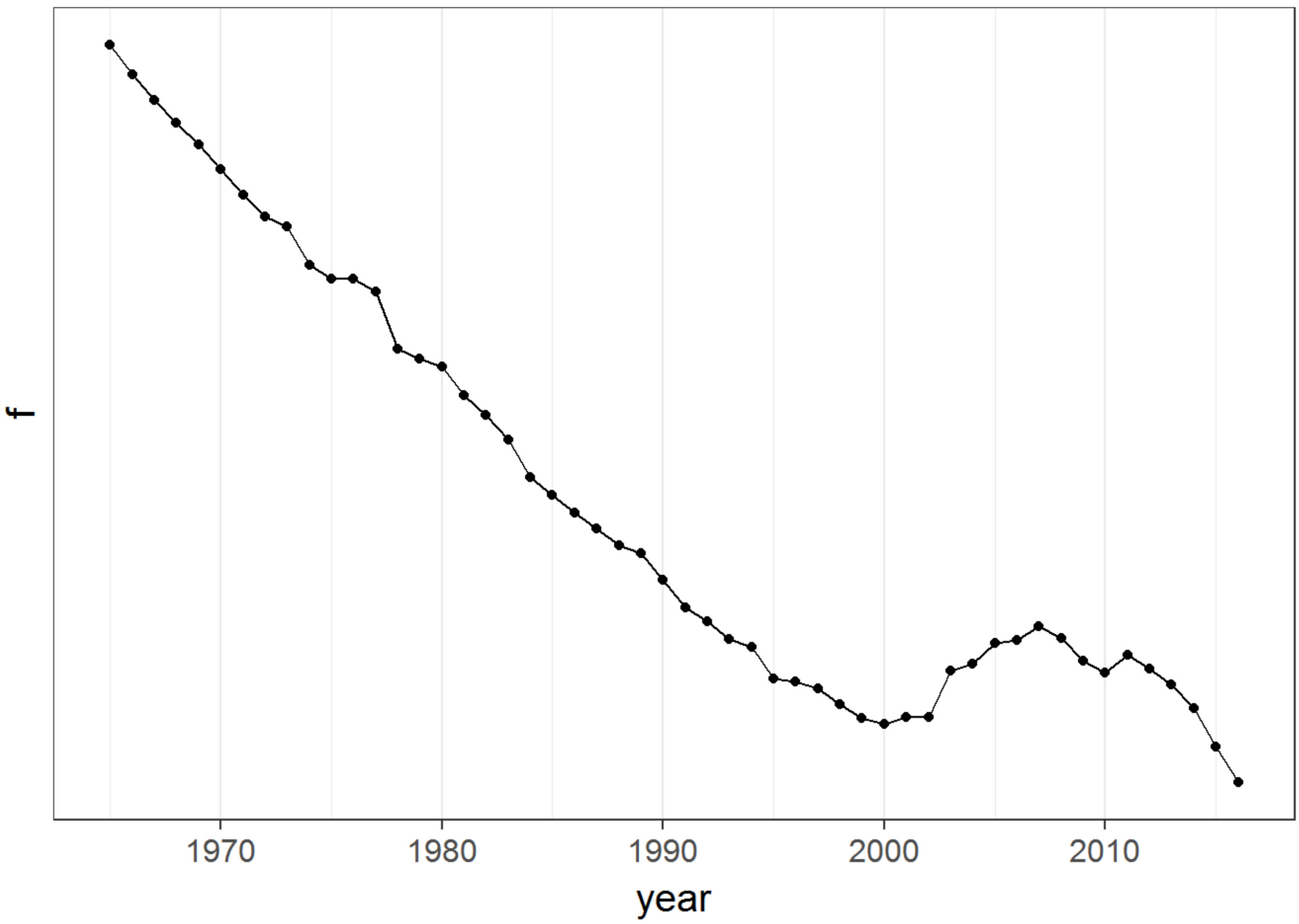

```
ggplot(world_data, aes(x = year, y= g)) +
  geom_line() + geom_point() +
  scale_y_log10()
```




```
ggplot(world_data, aes(x = year, y= e)) +
  geom_line() + geom_point() +
  scale_y_log10()
```




```
ggplot(world_data, aes(x = year, y= f)) +
  geom_line() + geom_point() +
  scale_y_log10()
```




```r
# average annual growth rate of per-capita GDP, in percent per year
P_fit = lm(log(P)~ year, data = world_data)
rate_P = summary(P_fit)$coefficients['year', 'Estimate']

g_fit = lm(log(g)~ year, data = world_data)
rate_g = summary(g_fit)$coefficients['year', 'Estimate']

e_fit = lm(log(e)~ year, data = world_data)
rate_e = summary(e_fit)$coefficients['year', 'Estimate']

f_fit = lm(log(f)~ year, data = world_data)
rate_f = summary(f_fit)$coefficients['year', 'Estimate']

rates = tibble(variable = c("P", "g", "e", "f"),
               rate = c(world_rate_P, world_rate_g, world_rate_e, world_rate_f))
```

Discussion Questions

Do you anticipate a problem if we make policy by assuming that the Kaya identity variables will follow the black trend line for the next several decades?

It would seem that from a practical perspective, any change in the variables that would decrease rate of carbon emissions would be a benefit, so I will skip those possibilities. Possibilities that would increase the rate of emissions include economic intensification, such as some technology breakthrough, something like google server farms, that require enormous amounts of energy to run, but are so useful that they become a staple technology in our society. Or, some boon in the economy that dramatically increases per capita GDP and allows more people to afford to consume

more energy for luxuries. All of these possibilities would increase the rate of emissions and reduce the usefulness of the black trend line in predicting what our future economy and overall carbon emissions will look like.

How does the implied rate of decarbonization for each nation compare to the historical rate of decarbonzation (i.e., the trend in ef reported in the “Bottom up Analysis” table)? Which nation will have the hardest time meeting the emission goal with damaging its economy?

The United States emission goal of 73% reduction in emissions by 2050 with an necessary decarbonization rate of -2.3% is a much easier goal to reach than China’s. The United States decarbonization rate in 2016 was -2.17%. This requires the U.S. to pursue only about a 6% acceleration in their current decarbonzation rate. On the otherhand, China’s task of acheiving the necessary decarbonization rate to reach a 78% reduction of emissions by 2050 is much harder. China’s decarbonization rate in 2016 was -3.79%. Their necessary decarbonization rat eto reach their 2050 goal is -4.3%. This is 13.5% acceleration of the decarbization rate from the 2016 rate for China. It will be roughly 3 time more difficult for China to reach its decarbonization goal than the U.S., if the difficulty is taken to be a function of the percent increase in the acceleration of decarbonization efforts.

If look at the whole world, the 2016 decarbonization rate is -1.08%. The decarbonization rate necessary to meet the 2050 target is -4.32%. This looks like a heavy burden for the world economy unless aggressive measures are taken to reach the goal.