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Lockdown Responses to COVID-19

Violeta A. Gutkowski

**Decentralized Finance: On Blockchain- and
Smart Contract-Based Financial Markets**

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REVIEW

Volume 103 • Number 2

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127

Lockdown Responses to COVID-19

Violeta A. Gutkowski

153

Decentralized Finance: On Blockchain- and Smart Contract-Based Financial Markets

Fabian Schär

175

Understanding the Gender Earnings Gap: Hours Worked, Occupational Sorting, and Labor Market Experience

Maria Canon, Limor Golan, and Cody A. Smith

207

More Stories of Unconventional Monetary Policy

Christopher J. Neely and Evan Karson

Review

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Lockdown Responses to COVID-19

Violeta A. Gutkowski

This article describes the relationship between countries' lockdown responses to the COVID-19 pandemic and those countries' political rights and civil liberties, macroeconomic variables, and vulnerability to the virus. Political rights and civil liberties cannot explain the differences in lockdown timing across countries. Countries with high contagion exposure due to weak water sanitation and weak health systems locked down their economies as fast as possible to reduce contagion. However, countries more vulnerable to COVID-19 due to large fractions of elderly and smokers in the population did not respond differently from less-vulnerable countries. Interestingly, macroeconomic variables that did affect the timing of lockdowns were the sizes of a country's financial and trading sectors, even when differences in income and population density are taken into account. (JEL C10, H4, I18)

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1 INTRODUCTION

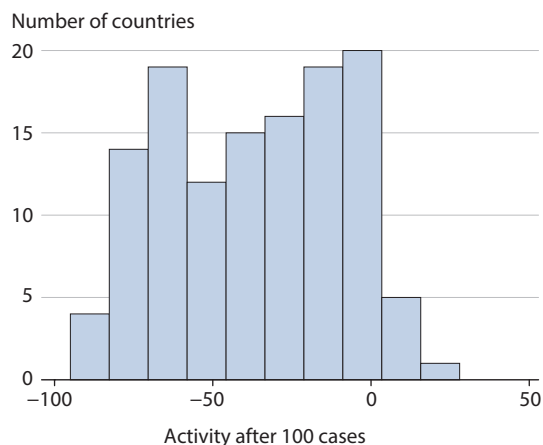
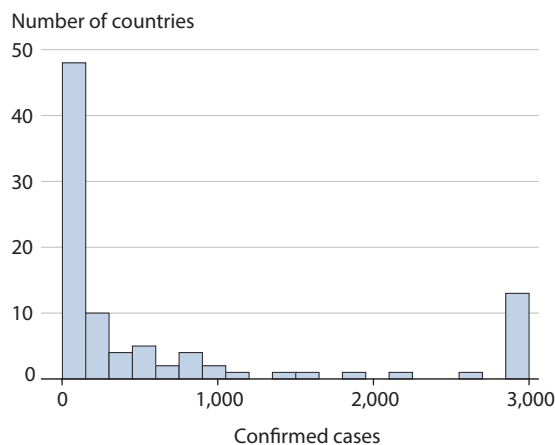
Why did some countries lock down their economies faster than others? Was lockdown speed related to a country's economic condition, democratic rights and civil liberties, or vulnerability to contagion and death? This article aims at understanding differences across countries in response to the COVID-19 pandemic, focusing on lockdown speed.

Figure 1A shows that there is dispersion in countries' responses to COVID-19. After having 100 confirmed cases, some countries remained fully open, while others had closed their economy even before reaching this point. In addition, while many countries locked down their economy after having a "sufficient" number of confirmed cases, as shown in Figure 1B, what each country considered *sufficient* seems to vary. For many countries 100 cases was enough, while for others 2,000 cases was not enough to restrict activity.

Recently, a wide literature combining economic models with the SIR model of contagion, used by public health specialists, has highlighted the trade-off between reducing economic activity by reducing social interaction at businesses and reducing the rate of infections. At

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Figure 1**Country Containment Responses to COVID-19****A. Dispersion in responses to COVID-19****B. Confirmed cases before lockdown**

NOTE: The lockdown measure in Panel B accounts for a country's economic activity falling at least 65 percent relative to the baseline. Note that while retail and recreation activity is positively correlated with economic activity, a 65 percent fall in that activity does not imply a fall in overall economic activity of the same degree.

SOURCE: Retail and recreation activity constructed using Google's (2020) "COVID-19 Community Mobility Reports."

the heart of the standard SIR model, there is a matching function that mixes susceptible individuals (S) with infected individuals (I).¹ Because private and public returns to social distancing differ due to externalities not taken into account by private agents, intervention could be desirable. Farboodi, Jarosch, and Shimer (2020) show that optimal policy reduces social interaction immediately relative to laissez-faire where individuals only reduce activity once the risk of infection becomes nonnegligible. Optimal social distancing starts as soon as the disease emerges, immediately imposing social distancing, for example, through stay-at-home orders. This sudden drop in activity delays the spread of infection and hence "buys time." That is, prior to development of a cure, social distancing enormously reduces expected fatalities and yields a substantial welfare gain, albeit at the cost of a reduction in social and economic activity.

The first and main hypothesis of this study is that lockdown timing and intensity in response to the pandemic can be explained by country differences in political rights and civil liberties. The lack of political rights and civil liberties can improve the externality problem. In other words, less individual liberty might imply more coordination and compliance, making the solution to the problem closer to the social optimum.

On one hand, on January 23, 2020, with a population of more than 11 million and less than 500 confirmed cases, Wuhan, China, was the first city to lock down; several other cities in the province of Hubei, China, followed immediately. On the other hand, on March 19, with a population of 36 million and already more than 1,000 confirmed cases, California was the first U.S. state to issue a statewide stay-at-home order.² China and the United States have very

different degrees of civil liberties, and stay-at-home orders have been of different intensities and at different points in time. For example, while many cities in China faced a full quarantine where people were not allowed to leave their homes, this did not happen at any point in the United States.

Disparity in the responses of the United States and China to COVID-19 could be driven by the differences in the countries' individual liberties. How did countries between these two extremes respond to COVID-19? I would expect to see that countries with high levels of freedom, political rights, and civil liberties would take significantly longer to force their population to quarantine and issue lockdowns. However, I do not find evidence to support the idea that countries with lower levels of freedom responded faster to the pandemic through lockdowns.

This finding is consistent with Frey, Chen, and Presidente (2020). Using the Oxford COVID-19 Government Response Tracker (OxCGRT), they test the belief that autocratic governments have been more effective in reducing the movement of people to curb the spread of COVID-19. They find that autocratic regimes imposed more-stringent lockdowns and relied more on contact tracing. However, they find no evidence that autocratic governments were more effective in reducing travel and find evidence to the contrary: Countries with democratically accountable governments introduced less-stringent lockdowns but were approximately 20 percent more effective in reducing mobility than their less-democratic counterparts who enforced the same level of policy stringency. Cronert (2020) investigates the institutional determinants of the timing of COVID-19-related school closures around the world, focusing on the role of democracy and administrative state capacity. That study finds that other things being equal, democratic countries tended to implement school closures quicker than those with a more authoritarian regime, while countries with high government effectiveness tended to take longer to implement school closures than those with less-effective state apparatuses. Similarly, Bosancianu et al. (2020) find that, to date, political and social variables such as populist governments, right-leaning governments, or women-led governments have little explanatory power over and above simple demographic and health indicators.

Second, I study whether differences in health systems and sanitation services as well as fatal vulnerability to the virus can explain the variation in country responses. The health status of the population measures the set of individuals potentially susceptible to the virus. In the SIR model, infected people transmit the virus to susceptible people at a rate that depends on the nature of the virus and on the frequency of social interactions. Populations with potentially better health might not get infected as easily from contact with individuals with the disease or if infected might have a lower likelihood of death. Additionally, populations with better sanitation services might also have a reduced likelihood of contagion. Similarly, hospital capacity could affect the payoff function of the policymaker. For example, some models assume that there is a capacity constraint in the health care system and that part of the reason to lock down is to avoid exceeding hospital capacity (Jones, Philippon, and Venkateswaran, 2020). One would expect that countries that are more vulnerable to contagion, have a weak health system to fight the virus, or have a large fraction of the population with pre-existing characteristics that increase the likelihood of death would respond faster to the pandemic. I find that countries that were highly exposed to fast COVID-19 contagion had a much faster response than coun-

tries that had better access to safe drinking water and sanitation. However, countries more vulnerable to COVID-19 due to a large fraction of elderly or smokers in the population do not seem to have responded faster than less-vulnerable countries. Nevertheless, after controlling for differences in income, none of these health- and sanitation-related variables can explain the variation in country responses to COVID-19. It is worth noting that this article is silent regarding whether differences in responses across countries are due to differences in sanitation and health systems or differences in incomes across countries, since these variables are highly correlated.

Early in 2020, the general expectation was that the coronavirus pandemic's effects would be more severe in developing countries than in advanced economies, on both the public health and economic fronts. According to Goldberg and Reed (2020), preliminary evidence as of June 2020 supports a more optimistic assessment. According to their investigation, to date, most low- and middle-income countries have had a significantly lower death toll per capita than richer countries, a pattern they attribute primarily to younger populations and limited obesity. On the economic front, emerging market and developing economies have seen massive capital outflows and large price declines for certain commodities, especially oil and non-precious metals; however, Goldberg and Reed (2020) suggest that these changes are in line with earlier commodity price shocks. They conclude that in the long run, the highest costs may be due to the indirect effects of virus containment policies on poverty, health, and education as well as to the effects of the accelerating deglobalization of emerging market and developing economies.

Finally, I look at whether economic variables that could affect the resources that countries have to navigate the impact of a substantial fall in economic activity could be responsible for the variation in responses. Macroeconomic variables could be changing the payoff function of the policymaker. Rich economies might have a different threshold for minimum consumption than poor countries; hence, they might be able to afford larger investment in health at the expense of the economy. I find that once differences in income and population density are taken into account, differences in the sizes of the financial and trading sectors can additionally explain variation in responses across countries. Demirguc-Kunt, Lokshin, and Torre (2020) provide an estimate of the economic impacts of the non-pharmaceutical interventions implemented by countries in Europe and Central Asia over the initial stages of the COVID-19 pandemic. Their results suggest that non-pharmaceutical interventions led to about a 10 percent decline in economic activity across the regions. On average, countries that implemented non-pharmaceutical interventions in the early stages of the pandemic appear to have had better short-term economic outcomes and lower cumulative mortality, compared with countries that imposed non-pharmaceutical interventions during the later stages of the pandemic. In part, this is because the interventions have been less stringent. Moreover, there is evidence that COVID-19 mortality at the peak of a local outbreak has been lower in countries that acted earlier.

The article is organized as follows. Section 2 reports the sources and the construction of the main variables used throughout the article. Section 3 presents the empirical analysis and main results. Section 4 concludes.

2 DATA

This article puts together databases from several sources. Data on COVID-19 total cases and deaths are from Roser et al. (2020), who collect this information as posted by the European Center for Disease Prevention and Control. Data on “activity” are from Google’s (2020) “COVID-19 Community Mobility Reports.” I use changes in retail and recreation activity relative to January 2020 as the main measure of activity. This variable is highly correlated with other mobility measures in the dataset such as workplace mobility and transit station activity (see Figure A2 in the appendix). The relative fall in mobility accounts for the fall in activity overall, not necessarily just from measures imposed by local governments. Additionally, a fall in retail and recreation activity does not necessarily imply a fall in economic activity of the same degree, since many people continued working from home and attended on-line activities. Nevertheless, a substantial fall in activity relative to January 2020 indicates a significant change in the population’s behavior during the early months of the pandemic.

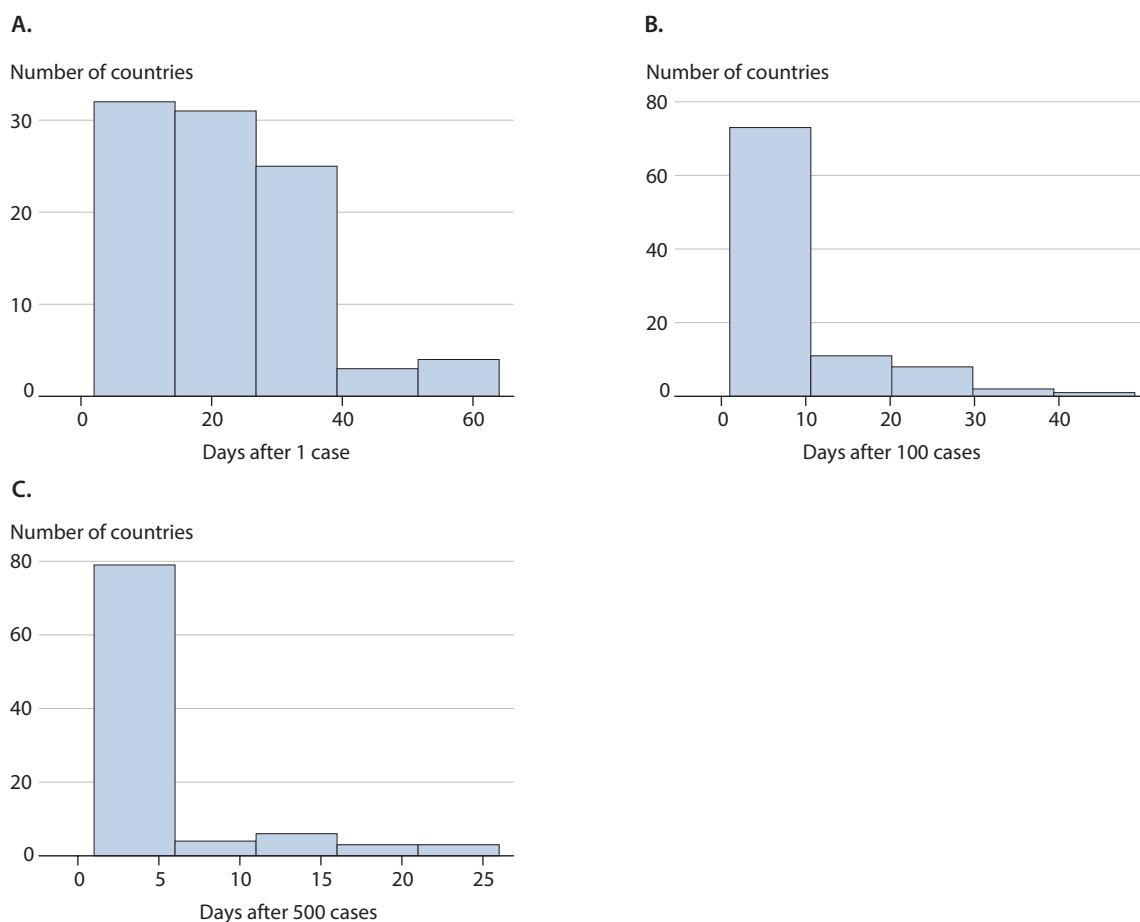
I use Freedom House’s “Freedom in the World 2020” global report on political rights and civil liberties and the freedom index therein to assess the degree of real-world rights and freedoms enjoyed by individuals within each country, which I call *freedom*. Given wide variation in government containment measures in response to COVID-19, the goal is to assess whether differences in the speeds of quarantine and lockdown measures can be explained by differences in the degree of freedom. I would expect to see that countries that have high levels of freedom would take significantly longer to engage their population into quarantines and lockdowns.

The variable *Freedom* comes from the Freedom House freedom index, which is constructed by analysts who use a broad range of sources, including news articles, academic analyses, reports from nongovernmental organizations, individual professional contacts, and on-the-ground research. The index is composed of a combination of points from political rights questions, including on the electoral process, political pluralism and participation, and the functioning of government, and from civil liberties questions, including on freedom of expression and beliefs, associational and organizational rights, rule of law and personal autonomy, and individual rights.³

Data on macroeconomic variables such as gross domestic product (GDP) per capita, unemployment, public debt, health, water access and sanitation, and population variables are from World Development Indicators (WDI, 2020). My dataset includes 128 countries with the daily evolution of total cases, deaths, and mobility from February 15 to June 27, 2020. Macroeconomic, health, and freedom data are the most-recent annual data, so I only have one observation per country. In the appendix, see Table A9 for a list of all countries included in the sample, Table A1 for descriptive statistics of the main variables used, and Table A10 for short descriptions and sources of all the variables used.

2.1 Lockdown

I construct a measure of lockdown speed as the number of days before the country reduces its activity by 65 percent. Figure 2 shows how long it took for countries to reduce their activity

Figure 2**Number of Country Lockdowns After 1, 100, and 500 Confirmed Cases**

NOTE: A lockdown is defined as at least a 65 percent fall in activity relative to the baseline.

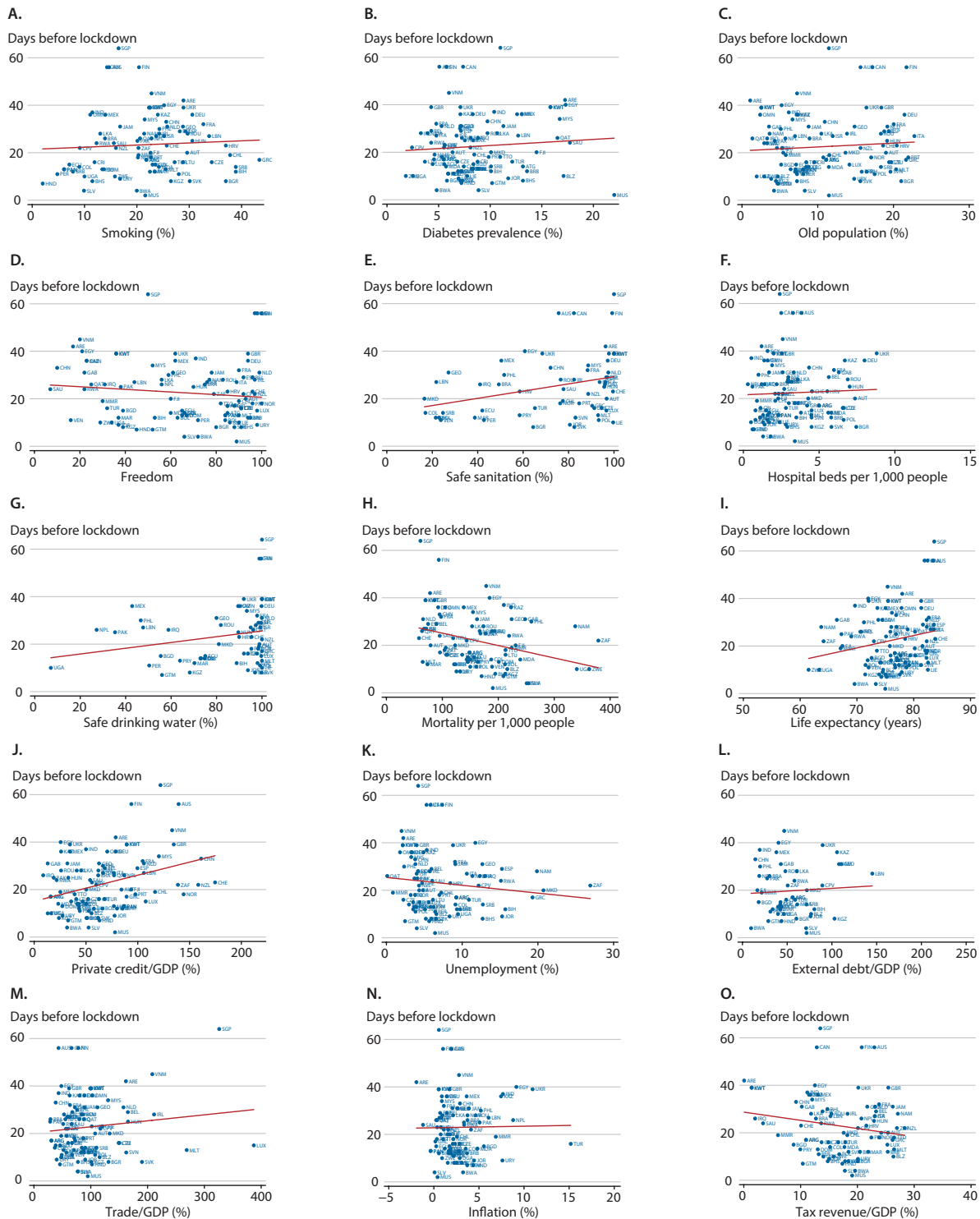
SOURCE: The lockdown measure is constructed using Google's (2020) "COVID-19 Community Mobility Reports."

to this level after the first confirmed case, 100 cases, and 500 cases. While most countries had substantially reduced their activity a few days after reaching 500 confirmed cases, there is more dispersion in their responses when the number of confirmed cases is lower. I study the correlation between lockdown speed (measured in days) and freedom in addition to several economic and health variables that could be related to vulnerability to COVID-19.

Various measures for government containment responses to the virus have been used in the literature. For example, Hale et al. (2020) construct a COVID-19 Government Response Stringency Index that is a composite measure of seven indicators related to school and workplace closings, international travel bans, restrictions on public events and gatherings, and stay-at-home requirements, among others. The lockdown measure used in this article is not directly related to government measures per se but is the likelihood of lockdown measures

Figure 3

Correlation of Lockdown Speed



NOTE: Correlation between lockdown speed and health or economic vulnerability. y-axes: Days between first COVID-19 case and lockdown (65 percent fall in activity). x-axes: See Table A10 for descriptions of measurements.

Table 1**Correlation Between Lockdown Speed and Health or Economic Vulnerability**

Life expectancy	Freedom	Political rights	Civil liberties
1.003*** (0.1690)	0.065 (0.0394)	0.146 (0.0907)	0.112 (0.0680)
Smoking	Old population	Population density	Diabetes prevalence
0.127 (0.1210)	0.584*** (0.1620)	0.000887 (0.00404)	0.180 (0.2520)
Safe drinking water	Safe sanitation	Hospital beds per 1,000 people	Mortality
0.156*** (0.0511)	0.126*** (0.0309)	0.447 (0.5080)	−0.0593*** (0.0125)
Trade/GDP	External debt/GDP	Unemployment	Private credit/GDP
0.012 (0.0179)	−0.058 (0.0338)	−0.408** (0.1870)	0.122*** (0.0219)
GDP per capita	Financial sector credit/GDP	Tax revenue/GDP	Public debt/GDP
3.983*** (0.6590)	0.115*** (0.0171)	−0.179 (0.1750)	−0.005 (0.0548)

NOTE: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Lockdown speed is days between the first confirmed COVID-19 case and a 65 percent fall in activity.

enforcing changes in the population's behavior. Nevertheless, Figure A1 shows that lockdown speed based on this measurement is highly correlated with the speed or timing that would result from using the Hale et al. (2020) Stringency Index.

Figure 3 plots the main variables of interest—freedom, macroeconomic, and health conditions variables—against the measure of lockdown speed; Table 1 shows the significance of these correlations, taking into account that countries had different lockdown starting dates. Note that a significant positive correlation implies a significantly longer time until lockdown. For example, the significant positive correlation for *life expectancy* implies that countries with a higher life expectancy took significantly longer to lock down than countries with a lower life expectancy.

I find that countries that were more vulnerable to contagion achieved faster non-pharmaceutical measures to reduce the probability of the spread of the pandemic by locking down their economies earlier. In particular, countries with better access to safe sanitation and drinking water, higher life expectancy, and lower mortality rates responded more slowly to the pandemic. However, countries more vulnerable to the virus due to health conditions, such as large fractions of older adults, smokers, or diabetics in the population, did not respond faster than less-vulnerable countries.⁴ Finally, richer countries with a larger financial sector took longer to lock down their economies, while other macroeconomic conditions such as the tax-revenue-to-GDP ratio, public debt, and political rights and civil liberties were uncorrelated with the decision to lock down.

3 EMPIRICAL STRATEGY

So far I have provided a description of lockdowns across countries. What could be driving the variation in country responses to COVID-19? At first sight, it seems that richer countries (in per capita terms)—with higher life expectancy and a large fraction of the population with access to safe drinking water and sanitation—took longer to respond. Can the degree of political rights and civil liberties explain differences in lockdown speeds across countries? Can the variation in economic conditions explain the differences? Or can the ease of contagion and the vulnerability of the population to the disease explain the differences?

A wide literature combining economic models with the SIR model of contagion used by public health specialists has highlighted the trade-off between reducing economic activity by reducing social interaction and reducing the rate of infections. At the heart of the standard SIR model, there is a matching function that mixes susceptible individuals (S) with infected individuals (I). Because private and public returns from social distancing differ due to externalities not taken into account by private agents, intervention could be desirable. The lack of political rights and civil liberties could reduce the externality problem. In other words, less individual liberty might imply more coordination and compliance, making the solution to the problem closer to the social optimum. The health status of the population measures the set of potentially susceptible individuals; thus, populations with a potentially better health status might be less likely to get infected from contact with individuals with the disease. Additionally, hospital capacity as well as macroeconomic variables can change the payoff function of the policymaker.

I find that freedom cannot explain differences in behavior across countries. Countries with a larger private-credit-to-GDP ratio took significantly longer to reduce their activity, probably because the cost of locking down the economy was higher. Additionally, countries with a larger trading sector were faster at implementing measures against COVID-19 contagion. Finally, countries more vulnerable to contagion were faster at implementing effective containment measures against COVID-19, while countries with populations more vulnerable to death from COVID-19 due to pre-existing characteristics do not seem to have behaved differently from less-vulnerable countries. However, once GDP per capita is taken into account, these differences in behavior to suppress contagion are no longer significant.

3.1 Freedom, Political Rights, and Civil Liberties

First, I test whether countries with higher levels of freedom took longer to lock down. I perform the following analysis:

$$Days_i = \beta_0 + \beta_1 Freedom + \beta_2 X_i + \epsilon_i.$$

The dependent variable is days between the day in which the first 100 cases were confirmed and the day in which the country had reached a large lockdown (activity fell 65 percent relative to the baseline in January 2020). The main explanatory variable to assess the degree of real-world rights and freedoms enjoyed by individuals within each country is *Freedom*. One could think that given the substantial polarity in the responses of the United States and China, civil

Table 2**Civil Freedom and Lockdown Timing**

	(1) L65_day1	(2) L65_day100	(3) L65_day500	(4) L65_day100	(5) L65_day100	(6) L50_day100	(7) L80_day100
Freedom	0.0174 (0.0371)	−0.0933 (0.0606)	−0.0103 (0.0289)			−0.0067 (0.0259)	−0.0098 (0.0790)
Political rights				−0.177 (0.130)			
Civil liberties					−0.179 (0.106)		
GDP per capita	1.187 (1.734)	5.031** (1.987)	2.458* (1.310)	4.741** (1.901)	5.213** (2.005)	3.386*** (0.604)	4.879* (2.747)
Population density	0.00135 (0.00395)	0.00229 (0.00485)	0.00059 (0.00264)	0.00230 (0.00504)	0.00230 (0.00472)	0.00146 (0.00214)	−0.00250 (0.00612)
Constant	−5.09 (14.84)	−33.86** (15.29)	−18.65* (10.60)	−32.63** (14.90)	−34.66** (15.40)	−23.90*** (5.56)	−31.37 (24.03)
Observations	92	92	92	92	92	113	60
R ²	0.521	0.625	0.621	0.617	0.631	0.924	0.891

NOTE: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. *LXdayC*: X percent fall in activity after the first C COVID-19 case(s) confirmed. These regressions include time fixed effects to account for differences across countries in the dates of the first confirmed COVID-19 case.

liberties could account for the differences in country responses to COVID-19. A positive and significant coefficient β_1 would imply that countries with a higher level of freedom took longer to enforce non-pharmaceutical measures to protect their population from the spread of the disease. X_i is a vector of control variables that includes the logarithm of GDP per capita and population density.

Table 2 shows the results for this analysis. *LXdayC* stands for a lockdown that implied an X percent fall in activity after the first C confirmed case(s). After controlling for GDP per capita and population density, none of the variables related to levels of *Freedom*—the freedom index, political rights index, or civil liberties index—can explain differences in lockdown speeds. This finding is robust to using partial (50 percent) and extreme (80 percent) lockdown measures (Columns 6 and 7 of Table 2) as well as considering days until the first 500 confirmed cases (Column 3 of Table 2).⁵ My results are in line with the findings of Hale et al. (2020) and Frey, Chen, and Presidente (2020). Additionally, these results are robust to controlling by region, clustering at the region level, and analyzing different combinations of lockdown intensity and confirmed cases. These results are also robust when I allow the model to be nonlinear; Table A3 in the appendix provides analysis under different scenarios to support this finding.

3.2 Macroeconomic Variables

Next, I test whether macroeconomic variables can explain the variation in responses across countries, specifically, the public debt-to-GDP ratio, the unemployment rate, openness

Table 3

Macroeconomic Variables and Lockdown Timing

	L65_day100					
	(1)	(2)	(3)	(4)	(5)	(6)
Trade/GDP	−0.0435* (0.0241)					
Public debt/GDP		−0.0563 (0.0713)				
Unemployment			−0.242 (0.209)			
External debt/GDP				−0.0647 (0.0530)		
Financial sector credit/GDP					0.0755*** (0.0236)	
Private credit/GDP						0.0723*** (0.0230)
GDP per capita	4.557*** (1.483)	5.401* (2.785)	3.914** (1.422)	3.648 (2.475)	2.226* (1.139)	2.610** (1.140)
Population density	0.00550 (0.00434)	0.00255 (0.00965)	0.00101 (0.00567)	0.00969** (0.00462)	0.00121 (0.00424)	0.00322 (0.00474)
Constant	−32.26** (12.49)	−39.68 (24.53)	−27.63** (12.79)	−24.38 (19.07)	−20.41* (10.13)	−22.79** (10.50)
Observations	91	28	86	48	91	91
R ²	0.641	0.828	0.642	0.793	0.662	0.633

NOTE: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. $LXdayC$: X percent fall in activity after the first C cases confirmed. These regressions include time fixed effects to account for differences across countries in the dates of the first confirmed COVID-19 case.

to trade, or the size of the financial sector. Macroeconomic variables could be changing the payoff function of the policymaker. For example, one could think that countries more economically unstable would have taken longer to respond to COVID-19 due to the devastating economic consequences a lockdown could bring and their scarce resources to navigate the expected economic downturn.

Following a similar exercise as before,

$$Days_i = \beta_0 + \beta_1 MacroVar + \beta_2 \mathbf{X}_i + \epsilon_i.$$

I regress the number of days it took each country after its first 100 confirmed cases to reach activity 65 percent lower than it had in January 2020. Table 3 shows the main results. Note that a positive and significant coefficient β_1 implies a significantly slower response to COVID-19.

I find that countries with a larger financial sector took significantly longer than other countries to reduce their activity. This is true using several measures of financial sector such as the private credit-to-GDP ratio, financial sector credit-to-GDP ratio, or private credit provided by banks-to-GDP ratio (see Tables A4 and A5 in the appendix).

Surprisingly, macroeconomic variables such as the unemployment rate, external debt to GDP, inflation, and tax revenue to GDP (among others) do not explain the variation in country responses to COVID-19. One would have expected that countries would be concerned about the economic consequences of lockdowns. What I observe is that countries with a larger financial sector took significantly longer to lock down their economies, probably due to the fears of repeating the previous large financial crisis. In addition, countries with a higher trade-to-GDP ratio reacted faster than countries with a lower degree of trade. Tables A4 and A5 in the appendix provide robustness analysis that takes into account regional fixed effects and different combinations of lockdown intensity and confirmed cases. These tables also include other macroeconomic variables not included in Table 3; however, they do not have any explanatory power for differences in country responses to COVID-19.

3.3 Health and Sanitation Variables

In this section, I perform a similar analysis as before but now look into the health vulnerability and sanitation variables. In the SIR model, infected people transmit the virus to susceptible people at a rate that depends on the nature of the virus and on the frequency of social interaction. Populations with a potentially better health status are less likely to get infected from contact with individuals with the disease or if infected might have a lower likelihood of death. I find that, surprisingly, countries more vulnerable to COVID-19 due to large fractions of older adults, smokers, and/or diabetics in the population did not respond differently from less-vulnerable countries. The analysis I conduct is the following:

$$Days_i = \beta_0 + \beta_1 HealthVar + \beta_2 \mathbf{X}_i + \epsilon_i.$$

Results can be found in Table 4. Although contagion variables such as water sanitation, access to drinking water, and the mortality rate significantly correlate with lockdown speed,⁶ once GDP per capita is taken into account, these variables lose explanatory power. It is worth mentioning that this analysis is silent about whether differences in the responses across countries are due to differences in sanitation and health systems or differences in income across countries, since these variables are highly correlated. Also, note that a negative coefficient on access to drinking water implies that countries with better access to drinking water took significantly fewer days to lock down their economies. Nevertheless, this significance is not robust to different measures of lockdown intensity.⁷

If we allow the model to be nonlinear to better fit the data, mortality becomes statistically significant—with a negative coefficient. That is, countries with a higher mortality rate locked down their economies significantly faster (see Table A6). Note that while the significance of mortality is robust to different levels of lockdown intensity and confirmed cases, the significance of the coefficient on the smoking population is not.

Finally, it would be interesting to know if richer countries with a higher health care capacity or better hygiene system actually took longer to lock down their economies relative to rich countries with a lower-quality hygiene system. Thus, I allow the model to have an interaction term between the health variable and GDP per capita:

Table 4**Health and Contagion Variables and Lockdown Timing**

	Days before large lockdown after 100 cases (L65_day100)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Smoking	0.0818 (0.0713)							
Old population		0.0741 (0.2550)						
Diabetes prevalence			0.0950 (0.2910)					
Safe drinking water				−0.0665* (0.0381)				
Safe sanitation					0.0543 (0.0492)			
Hospital beds per 1,000 people						−0.468 (0.425)		
Mortality							−0.0280 (0.0186)	
Life expectancy								0.433 (0.457)
GDP per capita	4.195** (1.565)	3.626** (1.430)	3.545** (1.478)	4.503*** (1.083)	2.651 (1.777)	4.075*** (1.451)	2.902** (1.131)	2.469* (1.434)
Population density	0.00235 (0.00588)	0.00240 (0.00554)	0.00021 (0.00686)	0.00215 (0.00696)	−0.000679 (0.00693)	0.00245 (0.00522)	−0.000567 (0.00557)	0.00182 (0.00552)
Constant	−33.91** (13.96)	−28.02** (12.56)	−26.64** (14.54)	−29.30*** (10.15)	−20.48 (15.02)	−29.91** (12.86)	−15.88 (10.50)	−49.32 (29.02)
Observations	83	93	93	58	56	91	82	93
R ²	0.626	0.594	0.518	0.832	0.827	0.621	0.558	0.607

NOTE: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. $LXdayC$: X percent fall in activity after the first C cases confirmed. These regressions include time fixed effects to account for differences across countries in the dates of the first confirmed COVID-19 case.

$$Days_i = \beta_0 + \beta_1 HealthVar + \beta_2 GDP + \beta_3 HealthVar * GDP + \beta_4 X_i + \epsilon_i.$$

If β_3 were positive and significant, it would imply that richer countries with a better health care system took longer to lock down their economies, providing evidence to support differences in the payoff function of the policymaker that can be incorporated into the SIR model. Nevertheless, I do not find supportive evidence for this statement (Table 5), and this finding is robust to different levels of lockdown intensity and confirmed cases.

4 CONCLUSION

To sum up, this article combines several databases to study whether civil liberties and political rights influenced country responses to the pandemic. I find that different levels of

Table 5**Health and Contagion Variables Interaction with GDP**

	(1) L65_day100	(2) L65_day100	(3) L65_day100	(4) L80_day1	(5) L80_day1	(6) L80_day1
Hospital beds per 1,000 people	−4.147 (4.394)			−10.030 (15.880)		
Hospital beds per 1,000 people × GDP	0.423 (0.458)			1.140 (1.678)		
Safe sanitation		0.106 (0.603)			−1.432 (2.497)	
Safe sanitation × GDP		−0.004 (0.062)			0.165 (0.269)	
Safe drinking water			−0.412 (0.562)			−1.840 (1.952)
Safe drinking water × GDP			0.040 (0.063)			0.204 (0.240)
GDP per capita	2.500 (1.787)	2.199 (4.147)	1.009 (5.395)	−0.690 (6.121)	−10.330 (18.950)	−14.120 (24.520)
Population density	−0.00041 (0.00595)	−0.00364 (0.00712)	0.00162 (0.00686)	0.00126 (0.01040)	−0.00086 (0.01190)	−0.00365 (0.01380)
Constant	−15.69 (15.57)	−16.30 (37.20)	0.32 (47.01)	32.29 (54.83)	117.10 (167.50)	154.20 (202.70)
Observations	92	57	58	62	45	42
R ²	0.543	0.702	0.836	0.793	0.857	0.822

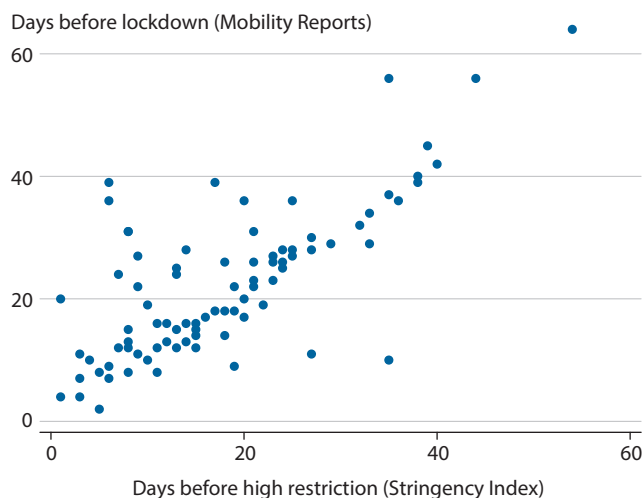
NOTE: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. $LXdayC$: X percent fall in activity after the first C case(s) confirmed. These regressions include time fixed effects to account for differences across countries in the dates of the first confirmed COVID-19 case.

political rights and civil liberties—freedom—cannot explain differences in lockdown timing across countries. Vulnerability to fast contagion seems to have been at the heart of lockdown decisions. The health and contagion variables are highly correlated with a country's income level. Thus, once GDP per capita is taken into account, most health and contagion variables cannot further explain differences in country responses to the pandemic. Interestingly, macroeconomic variables that did affect lockdown were the sizes of a country's financial and trade sectors, even when taking into account income and population density differences across countries. This finding suggests that fears of another financial crisis might have played an important role in how countries decided to manage the COVID-19 pandemic. I perform several robustness checks and show that the main results are robust to controlling for differences in the timing of a country's first confirmed case (by controlling for time fixed effects); regional differences (by controlling for regional fixed effects); and different measures of lockdown intensity, that is, activity falling by 50 percent, 65 percent, or 80 percent. ■

APPENDIX: FIGURES AND TABLES

Figure A1

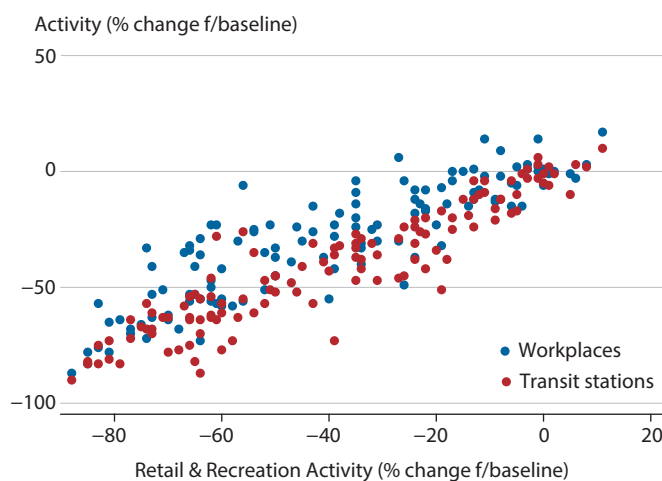
Correlation Between Mobility and Stringency Index



NOTE: x-axis: Days before a country reached a high level of restriction (65 percent fall in activity) using the Stringency Index. y-axis: Days to a 65 percent fall in activity (relative to January 2020) after the first confirmed COVID-19 case in a country. SOURCE: Activity is based on Google's (2020) "COVID-19 Community Mobility Reports." The Stringency Index is from Hale et al. (2020).

Figure A2

Correlation Between Mobility Variables



NOTE: Activity is measured as changes in mobility in retail and recreation, workspaces, and transit stations one day after the first 100 confirmed COVID-19 cases in a country relative to January 2020.

SOURCE: Activity is based on Google's (2020) "COVID-19 Community Mobility Reports."

Table A1**Descriptive Statistics: Explanatory Variables**

Variables	(1) Mean	(2) SD	(3) Min	(4) Max	(5) p5	(6) p50	(7) p95	(8) N
GDP per capita	8.92	1.41	6.00	11.61	6.57	8.95	10.97	128
Population density	155.80	212.50	1.98	1.45	6.68	83.48	528.00	127
Freedom	62.69	28.11	7.00	100.00	16.00	66.00	98.00	127
Political rights	25.02	12.59	0.00	40.00	2.00	27.00	40.00	127
Civil liberties	37.67	15.80	6.00	60.00	12.00	38.00	58.00	127
External debt (% of GDP)	53.32	35.81	9.71	253.90	18.19	42.97	107.60	73
Domestic credit to private sector by banks (% of GDP)	56.94	37.10	8.70	174.60	13.02	50.21	133.10	124
Financial sector credit (% of GDP)	76.76	50.71	6.98	271.70	19.77	64.46	176.70	123
Private credit (% of GDP)	61.76	41.80	8.70	187.20	13.09	52.54	144.60	123
Public debt (% of GDP)	59.90	41.30	0.05	196.40	14.18	51.42	141.40	37
Tax revenue (% of GDP)	16.76	6.39	0.02	33.37	6.02	16.03	26.46	108
Trade (% of GDP)	90.11	54.52	27.54	387.10	36.18	77.24	165.50	124
Unemployment	6.69	4.53	0.11	26.92	2.16	5.37	15.27	106
Smoking (% of population)	20.90	9.10	2.00	43.40	6.40	21.60	37.00	109
Old population (% of population)	9.89	6.75	1.09	27.58	2.39	7.27	21.02	128
Access to safe drinking water (% of population)	80.13	25.95	7.07	100.00	23.72	93.95	100.00	76
Access to safe sanitation (% of population)	71.16	28.43	9.61	100	18.71	82.41	99.65	73
Hospital beds per thousand people	3.14	2.54	0.10	13.05	0.50	2.40	8.00	119
Life expectancy	74.14	7.00	54.69	84.63	61.04	75.28	83.03	130
Mortality	180.10	81.65	58.20	406.20	65.56	171.90	341.80	116
NOTE: SD, standard deviation.								

Table A2**Descriptive Statistics: Days to Lockdown**

	Mean	SD	Min	Max	p5	p50	p95	N
Large lockdown: 500 cases (days) (L65_day500)	3.65	5.80	1.00	26.00	1.00	1.00	19.00	95.00
Large lockdown: 100 cases (days) (L65_day100)	7.05	8.96	1.00	49.00	1.00	3.00	25.00	95.00
Large lockdown: 1 case (days) (L65_day1)	22.33	12.57	2.00	64.00	7.00	20.00	45.00	95.00
Partial lockdown: 100 cases (days) (L50_day100)	6.86	12.67	1.00	105.00	1.00	1.00	32.00	118.00
Extreme lockdown: 100 cases (days) (L80_day100)	13.53	14.54	1.00	69.00	1.00	8.50	41.00	64.00
Extreme lockdown: 500 cases (days) (L80_day500)	7.98	11.41	1.00	62.00	1.00	1.50	29.00	64.00
NOTE: SD, standard deviation.								

Table A3**Civil Freedom and Lockdown Timing**

	L65_day1	L65_day100	L65_day500	L65_day100	L65_day100	L50_day100	L80_day100	L65_day100
Freedom	0.0151 (0.0888)	-0.0577 (0.0308)	-0.0060 (0.0213)			-0.0155 (0.0135)	0.0640 (0.0556)	-0.2520 (0.2940)
Political rights				-0.0857 (0.0747)				
Civil liberties					-0.1280* (0.0534)			
Freedom 2								0.0014 (0.0022)
GDP per capita	3.227 (1.707)	4.365** (1.234)	1.982 (1.043)	4.135** (1.165)	4.549** (1.318)	2.617** (0.864)	2.971 (1.462)	4.232** (1.796)
Population density	-0.00151 (0.00449)	0.00171 (0.00534)	0.00085 (0.00328)	0.00152 (0.00532)	0.00184 (0.00536)	0.00048 (0.00125)	-0.00583** (0.00135)	0.00035 (0.00547)
Constant	-1.28 (24.98)	-24.26 (18.41)	-10.30 (13.10)	-23.81 (18.17)	-24.65 (18.61)	-13.76 (10.04)	-16.42 (9.96)	-17.03 (15.74)
Observations	92	92	92	92	92	113	60	93
R ²	0.615	0.664	0.639	0.660	0.668	0.936	0.909	0.625

NOTE: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. $LXdayC$: X percent fall in activity after the first C confirmed COVID-19 case(s). Freedom 2 is the squared term for Freedom. These regressions include time and region fixed effects to account for differences across countries in the dates of the first-reported COVID-19 case and regional differences.

Table A4

Macroeconomic Variables and Lockdown Timing

Days until partial lockdown date after 100 cases (L50_day100)								
Trade/GDP	-0.0204 (0.0368)							
Public debt/GDP		-0.0083 (0.0334)						
Tax revenue/GDP			-0.0770 (0.0677)					
Unemployment				-0.0545 (0.1270)				
External debt/GDP					-0.0603*** (0.0116)			
Financial sector credit/GDP						0.0662** (0.0154)		
Private credit/GDP							0.0594*** (0.0124)	
Private credit (by banks)/GDP								0.0622*** (0.0130)
GDP per capita	2.845* (1.116)	2.167 (1.027)	2.685** (0.820)	2.677** (0.866)	3.362*** (0.306)	1.014*** (0.131)	1.467** (0.377)	1.466** (0.581)
Population density	0.00117 (0.00237)	0.00879 (0.02100)	0.00015 (0.00072)	8.06e-06 (0.00150)	0.00027 (0.00296)	-0.00224 (0.00113)	-0.00092 (0.00119)	-0.00094 (0.00147)
Constant	-16.74 (10.700)	-11.88 (9.918)	-14.16 (9.734)	-15.01 (10.480)	-17.25*** (3.351)	-6.28* (2.502)	-9.59 (6.049)	-9.41 (7.400)
Observations	111	35	98	101	63	109	109	111
R ²	0.942	0.947	0.941	0.942	0.921	0.956	0.950	0.947

NOTE: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. $LXdayC$: X percent fall in activity after the first C confirmed COVID-19 cases. These regressions include time and region fixed effects to account for differences across countries in the dates of the first-reported COVID-19 case and regional differences.

Table A5**Macroeconomic Variables and Lockdown Timing**

Days until extreme lockdown date after 100 COVID-19 cases (L80_day100)							
Trade/GDP	-0.0823*** (0.0141)						
Public debt/GDP	0.0548 (0.117)						
Unemployment	-0.200 (0.242)						
External debt/GDP	-0.0690 (0.0303)						
Financial sector credit/GDP	0.0550** (0.0190)						
Private credit/GDP	0.0727** (0.0212)						
Private credit (by banks)/GDP	0.0595*** (0.0073)						
GDP per capita	4.260** (1.415)	4.153** (1.054)	3.127** (1.055)	1.928 (1.826)	2.145** (0.533)	2.188* (0.901)	2.340* (0.902)
Population density	-0.00146 (0.00241)	-0.00580 (0.00968)	-0.00712*** (0.00149)	0.00116 (0.00230)	-0.00725* (0.00272)	-0.00548 (0.00334)	-0.00602 (0.00368)
Constant	-18.11 (12.75)	-27.06** (6.29)	-10.63 (11.87)	-3.84 (17.34)	-10.42 (5.70)	-12.83 (6.20)	-10.92 (8.33)
Observations	62	20	59	27	62	62	62
R ²	0.939	0.959	0.906	0.988	0.911	0.913	0.908

NOTE: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. $LXdayC$: X percent fall in activity after the first C confirmed COVID-19 cases. These regressions include time and region fixed effects to account for differences across countries in the dates of the first-reported COVID-19 case and regional differences.

Table A6**Nonlinear Specification for Health and Contagion Variables**

Days before large lockdown after 100 COVID-19 cases (L65_day100)					
Smoking	0.613*				
	(0.3450)				
Smoking 2	−0.011*				
	(0.006)				
Old population		−0.661			
		(1.240)			
Old population 2		0.029			
		(0.0489)			
Mortality			−0.135**		
			(0.0617)		
Mortality 2			0.000250*		
			(0.0001)		
Life expectancy				−3.807	
				(5.347)	
Life expectancy 2				0.029	
				(0.0374)	
Hospital beds per 1,000 people					−1.838
					(1.8070)
Hospital beds per 1,000 people 2					0.209
					(0.1970)
GDP per capita	3.754**	3.431**	1.871	1.739	3.868**
	(1.690)	(1.421)	(1.106)	(1.676)	(1.691)
Population density	−3.69e-05	−8.68e-05	−0.00417	−0.000268	4.40e-07
	(0.00686)	(0.00589)	(0.00627)	(0.00686)	(0.00621)
Constant	−34.25**	−22.05	3.91	112.70	−25.90*
	(14.12)	(13.31)	(13.00)	(196.70)	(14.10)
Observations	84	94	83	94	92
R ²	0.549	0.523	0.507	0.536	0.543

NOTE: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. $LXdayC$: X percent fall in activity after the first C confirmed COVID-19 cases. These regressions include time and region fixed effects to account for differences across countries in the dates of the first-reported COVID-19 case and regional differences. X^2 is the squared term for X .

Table A7**Robustness: Health and Contagion Variables and Lockdown Timing**

Days until extreme lockdown date after 500 cases (L65_day500)							
Smoking	−0.0060 (0.0537)						
Old population		0.2350 (0.2050)					
Safe drinking water			−0.0273 (0.0463)				
Safe sanitation				0.0129** (0.0031)			
Hospital beds per 1,000 people					−0.4360 (0.2690)		
Mortality						−0.0103 (0.0093)	
Life expectancy							0.4060* (0.1880)
GDP per capita	2.109* (0.951)	1.729 (1.121)	3.028** (0.993)	2.697* (0.992)	2.186* (0.854)	1.587 (1.246)	0.887* (0.413)
Population density	0.00105 (0.00349)	0.00069 (0.00336)	0.00079 (0.00112)	0.00105 (0.00138)	0.00071 (0.00310)	−0.00179 (0.00110)	8.16e-05 (0.00324)
Constant	−12.09 (12.12)	−11.68 (11.38)	−29.83** (9.16)	−21.76* (9.78)	−12.10 (10.70)	−9.50 (8.19)	−32.86 (21.09)
Observations	83	93	58	56	91	82	93
R ²	0.644	0.648	0.846	0.846	0.671	0.547	0.661

NOTE: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. $LXdayC$: X percent fall in activity after the first C confirmed COVID-19 cases. These regressions include time and region fixed effects to account for differences across countries in the dates of the first-reported COVID-19 case and regional differences.

Table A8**Robustness: Health and Contagion Variables and Lockdown Timing**

Days until extreme lockdown date after 100 cases (L80_day100)							
Smoking	0.052 (0.280)						
Old population		0.966** (0.318)					
Safe drinking water			0.033 (0.133)				
Safe sanitation				-0.115 (0.057)			
Hospital beds per 1,000 people					1.632 (0.893)		
Mortality						0.00950 (0.00993)	
Life expectancy							0.371 (0.869)
GDP per capita	2.799 (1.779)	1.291 (0.632)	5.473*** (0.686)	6.004*** (1.270)	2.811** (0.865)	4.511* (1.885)	2.022 (1.567)
Population density	-0.00493** (0.00127)	-0.01010 (0.00584)	-0.00521 (0.00321)	-0.00707 (0.00352)	-0.00543 (0.00343)	-0.00739 (0.00507)	-0.00738 (0.00574)
Constant	-11.24 (14.33)	-4.82 (7.41)	-35.47* (13.06)	-33.02** (9.69)	-14.03 (10.04)	-25.59 (15.79)	-29.86 (52.09)
Observations	54	63	42	44	61	56	63
R ²	0.916	0.916	0.905	0.944	0.915	0.920	0.904

NOTE: Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. $LXdayC$: X percent fall in activity after the first C confirmed COVID-19 cases. These regressions include time and region fixed effects to account for differences across countries in the dates of the first-reported COVID-19 case and regional differences.

Table A9**List of Countries**

Afghanistan	Ecuador	Libya	Romania
Angola	Egypt	Lithuania	Russia
Antigua and Barbuda	El Salvador	Luxembourg	Rwanda
Argentina	Estonia	Macedonia	Saudi Arabia
Aruba	Fiji	Malaysia	Senegal
Australia	Finland	Mali	Serbia
Austria	France	Malta	Singapore
Bahamas	Gabon	Mauritius	Slovakia
Bahrain	Georgia	Mexico	Slovenia
Bangladesh	Germany	Moldova	South Africa
Barbados	Ghana	Mongolia	South Korea
Belarus	Greece	Morocco	Spain
Belgium	Guatemala	Mozambique	Sri Lanka
Belize	Guinea-Bissau	Myanmar	Sweden
Benin	Haiti	Namibia	Switzerland
Bolivia	Honduras	Nepal	Taiwan
Bosnia and Herzegovina	Hungary	Netherlands	Tajikistan
Botswana	India	New Zealand	Tanzania
Brazil	Indonesia	Nicaragua	Thailand
Bulgaria	Iraq	Niger	Togo
Burkina Faso	Ireland	Nigeria	Trinidad and Tobago
Cambodia	Israel	Norway	Turkey
Cameroon	Italy	Oman	Uganda
Canada	Jamaica	Pakistan	Ukraine
Cape Verde	Japan	Panama	United Arab Emirates
Chile	Jordan	Papua New Guinea	United Kingdom
China	Kazakhstan	Paraguay	United States
Colombia	Kenya	Peru	Uruguay
Costa Rica	Kuwait	Philippines	Venezuela
Cote d'Ivoire	Kyrgyzstan	Poland	Vietnam
Croatia	Laos	Portugal	Yemen
Czech Republic	Latvia	Puerto Rico	Zambia
Denmark	Lebanon	Qatar	Zimbabwe
Dominican Republic			

Table A10**Robustness: Health and Contagion Variables and Lockdown Timing**

Variable	Short description	Source
GDP per capita	GDP per capita (logs)	WDI (2020)
Trade/GDP	Trade (% of GDP)	WDI (2020)
External debt/GDP	External debt stocks (% of GDP)	WDI (2020)
Unemployment	Unemployment, total (% of total labor force)	WDI (2020)
Private credit/GDP	Domestic credit to private sector (% of GDP)	WDI (2020)
Public debt/GDP	Central government debt, total (% of GDP)	WDI (2020)
Banks private credit/GDP	Domestic credit to private sector by banks (% of GDP)	WDI (2020)
Financial sect. credit/GDP	Domestic credit provided by financial sector (% of GDP)	WDI (2020)
Tax revenue/GDP	Tax revenue (% of GDP)	Freedom House (2020)
Inflation	Inflation, consumer prices (annual %)	Freedom House (2020)
Political rights	Political rights category score (40 points)	Freedom House (2020)
Civil liberties	Civil liberties category score (60 points)	WDI (2020)
Freedom	Aggregate score for political rights and civil liberties categories (100 points)	WDI (2020)
Smoking	Smoking prevalence, total, ages 15+	WDI (2020)
Old population	Population ages 65 and above (% of total)	WDI (2020)
Population density	Population density (people per sq. km of land area)	WDI (2020)
Diabetes prevalence	Diabetes prevalence (type 1 or 2 diabetes) (% of population ages 20 to 79)	WDI (2020)
Safe drinking water	People using safely managed drinking water services (% of population)	WDI (2020)
Safe sanitation	People using safely managed sanitation services (% of population)	WDI (2020)
Hospital beds per 1,000 people	Hospital beds in public, private, general, and specialized hospitals and rehabilitation centers	WDI (2020)
Mortality	Mortality rate, adult males (per 1,000)	WDI (2020)
Life expectancy	Life expectancy at birth, total (years)	WDI (2020)
Total cases	Total confirmed cases	
L65_day100	Days before large lockdown (65% fall in activity) since first 100 confirmed COVID-19 cases	Roser et al. (2020)
L50_day100	Days before partial lockdown (50% fall in activity) since first 100 confirmed COVID-19 cases	Calculated using Google (2020)
L80_day100	Days before extreme lockdown (80% fall in activity) since first 100 confirmed COVID-19 cases	Calculated using Google (2020)
LXdayC	Days before X lockdown (X% fall in activity) since first C confirmed COVID-19 case(s)	Calculated using Google (2020)

NOTES

- ¹ Atkeson (2020) provides a good summary of this framework. The “R” of SIR is for recovered individuals, who are no longer contagious.
- ² Many counties within California had issued a “shelter in place” order a few days before.
- ³ See <https://freedomhouse.org/reports/freedom-world/freedom-world-research-methodology> for details and methodology used by Freedom House.
- ⁴ Moreover, these results show that the opposite is true: Countries with a higher fraction of older adults took significantly longer to lock down.
- ⁵ Many countries have never reached an extreme quarantine, thus there are fewer observations for the extreme-lockdown scenario.
- ⁶ This correlation is consistent with the fact that populations with a lower-quality hygiene system might have a higher rate of contagion
- ⁷ Robustness exercises can be found in Tables A7 and A8.

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Decentralized Finance: On Blockchain- and Smart Contract-Based Financial Markets

By Fabian Schär

The term decentralized finance (DeFi) refers to an alternative financial infrastructure built on top of the Ethereum blockchain. DeFi uses smart contracts to create protocols that replicate existing financial services in a more open, interoperable, and transparent way. This article highlights opportunities and potential risks of the DeFi ecosystem. I propose a multi-layered framework to analyze the implicit architecture and the various DeFi building blocks, including token standards, decentralized exchanges, decentralized debt markets, blockchain derivatives, and on-chain asset management protocols. I conclude that DeFi still is a niche market with certain risks but that it also has interesting properties in terms of efficiency, transparency, accessibility, and composability. As such, DeFi may potentially contribute to a more robust and transparent financial infrastructure. (JEL G15, G23, E59)

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1 INTRODUCTION

Decentralized finance (DeFi) is a blockchain-based financial infrastructure that has recently gained a lot of traction. The term generally refers to an open, permissionless, and highly interoperable protocol stack built on public smart contract platforms, such as the Ethereum blockchain (see Buterin, 2013). It replicates existing financial services in a more open and transparent way. In particular, DeFi does not rely on intermediaries and centralized institutions. Instead, it is based on open protocols and decentralized applications (DApps). Agreements are enforced by code, transactions are executed in a secure and verifiable way, and legitimate state changes persist on a public blockchain. Thus, this architecture can create an immutable and highly interoperable financial system with unprecedented transparency, equal access rights, and little need for custodians, central clearing houses, or escrow services, as most of these roles can be assumed by “smart contracts.”

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DeFi already offers a wide variety of applications. For example, one can buy U.S. dollar (USD)-pegged assets (so-called stablecoins) on decentralized exchanges, move these assets to an equally decentralized lending platform to earn interest, and subsequently add the interest-bearing instruments to a decentralized liquidity pool or an on-chain investment fund.

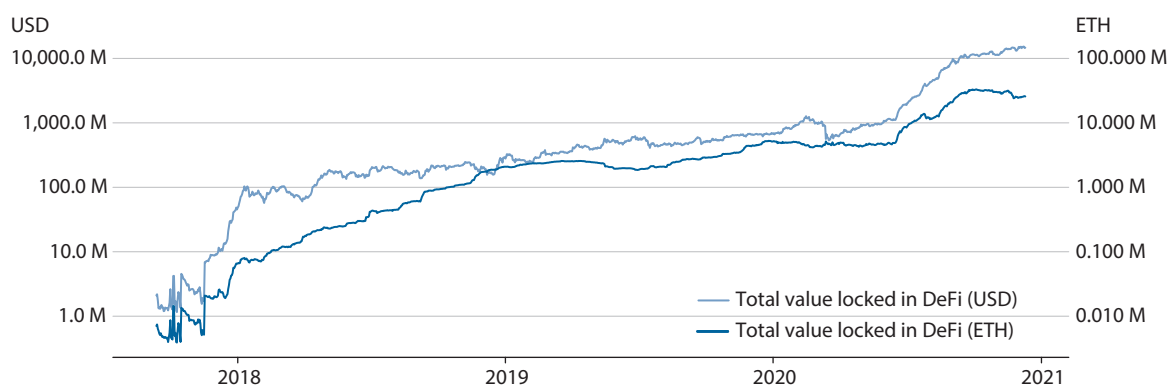
The backbone of all DeFi protocols and applications is smart contracts. Smart contracts generally refer to small applications stored on a blockchain and executed in parallel by a large set of validators. In the context of public blockchains, the network is designed so that each participant can be involved in and verify the correct execution of any operation. As a result, smart contracts are somewhat inefficient compared with traditional centralized computing. However, their advantage is a high level of security: Smart contracts will always be executed as specified and allow anyone to verify the resulting state changes independently. When implemented securely, smart contracts are highly transparent and minimize the risk of manipulation and arbitrary intervention.

To understand the novelty of smart contracts, we first must look at regular server-based web applications. When a user interacts with such an application, they cannot observe the application's internal logic. Moreover, the user is not in control of the execution environment. Either one (or both) could be manipulated. As a result, the user has to trust the application service provider. Smart contracts mitigate both problems and ensure that an application runs as expected. The contract code is stored on the underlying blockchain and can therefore be publicly scrutinized. The contract's behavior is deterministic, and function calls (in the form of transactions) are processed by thousands of network participants in parallel, ensuring the execution's legitimacy. When the execution leads to state changes, for example, the change of account balances, these changes are subject to the blockchain network's consensus rules and will be reflected in and protected by the blockchain's state tree.

Smart contracts have access to a rich instruction set and are therefore quite flexible. Additionally, they can store cryptoassets and thereby assume the role of a custodian, with entirely customizable criteria for how, when, and to whom these assets can be released. This allows for a large variety of novel applications and flourishing ecosystems.

The original concept of a smart contract was coined by Szabo (1994). Szabo (1997) used the example of a vending machine to describe the idea further and argued that many agreements could be “embedded in the hardware and software we deal with, in such a way as to make a breach of contract expensive...for the breacher.” Buterin (2013) proposed a decentralized blockchain-based smart contract platform to solve any trust issues regarding the execution environment and to enable secure global states. Additionally, this platform allows the contracts to interact with and build on top of each other (composability). The concept was further formalized by Wood (2015) and implemented under the name Ethereum. Although there are many alternatives, Ethereum is the largest smart contract platform in terms of market cap, available applications, and development activity.

DeFi still is a niche market with relatively low volumes—however, these numbers are growing rapidly. The value of funds that are locked in DeFi-related smart contracts recently crossed 10 billion USD. It is essential to understand that these are not transaction volume or market cap numbers; the value refers to reserves locked in smart contracts for use in various

Figure 1**Total Value Locked in DeFi Contracts (USD and ETH)**

NOTE: M, million.

SOURCE: DeFi Pulse.

ways that will be explained in the course of this paper. Figure 1 shows the Ether (ETH, the native cryptoasset of Ethereum) and USD values of the assets locked in DeFi applications.

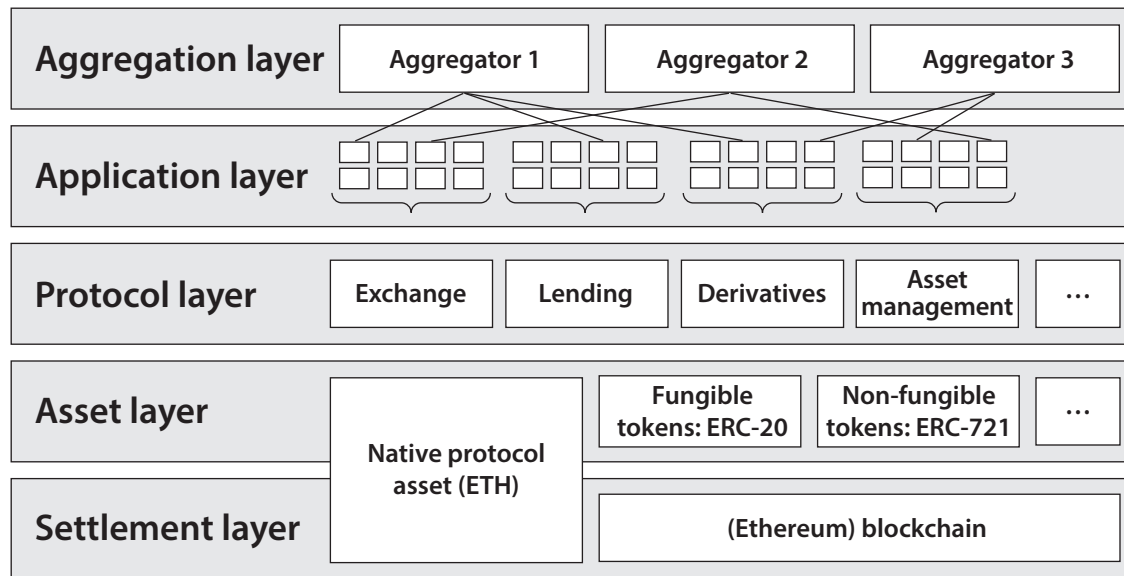
The spectacular growth of these assets alongside some truly innovative protocols suggests that DeFi may become relevant in a much broader context and has sparked interest among policymakers, researchers, and financial institutions. This article is targeted at individuals from these organizations with an economics or legal background and serves as a survey and an introduction to the topic. In particular, it identifies opportunities and risks and should be seen as a foundation for further research.

2 DeFi BUILDING BLOCKS

DeFi uses a multi-layered architecture. Every layer has a distinct purpose. The layers build on each other and create an open and highly composable infrastructure that allows everyone to build on, rehash, or use other parts of the stack. It is also crucial to understand that these layers are hierarchical: They are only as secure as the layers below. If, for example, the blockchain in the settlement layer is compromised, all subsequent layers would not be secure. Similarly, if we were to use a permissioned ledger as the foundation, any decentralization efforts on subsequent layers would be ineffective.

This section proposes a conceptual framework for analyzing these layers and studying the token and the protocol layers in greater detail.¹ It differentiates between five layers, as shown in Figure 2: the *settlement*, *asset*, *protocol*, *application*, and *aggregation* layers.

1. The *settlement layer* (Layer 1) consists of the blockchain and its native protocol asset (e.g., Bitcoin [BTC] on the Bitcoin blockchain and ETH on the Ethereum blockchain). It allows the network to store ownership information securely and ensures that any

Figure 2**The DeFi Stack**

state changes adhere to its ruleset. The blockchain can be seen as the foundation for trustless execution and serves as a settlement and dispute resolution layer.

2. The *asset layer* (Layer 2) consists of all assets that are issued on top of the settlement layer. This includes the native protocol asset as well as any additional assets that are issued on this blockchain (usually referred to as tokens).
3. The *protocol layer* (Layer 3) provides standards for specific use cases such as decentralized exchanges, debt markets, derivatives, and on-chain asset management. These standards are usually implemented as a set of smart contracts and can be accessed by any user (or DeFi application). As such, these protocols are highly interoperable.
4. The *application layer* (Layer 4) creates user-oriented applications that connect to individual protocols. The smart contract interaction is usually abstracted by a web browser-based front end, making the protocols easier to use.
5. The *aggregation layer* (Layer 5) is an extension of the application layer. Aggregators create user-centric platforms that connect to several applications and protocols. They usually provide tools to compare and rate services, allow users to perform otherwise complex tasks by connecting to several protocols simultaneously, and combine relevant information in a clear and concise manner.

Now that we understand the conceptual model, let us take a closer look at tokenization and the protocol layer. After a short introduction to asset tokenization, we will investigate decentralized exchange protocols, decentralized lending platforms, decentralized derivatives,

Table 1**Listed Tokens and Total Token Market Cap by Blockchain Platform**

Platform	Number		Market capitalization	
	Absolute	Relative %	Absolute (USD)	Relative %
Ethereum	1,793	86.74	55,071,650,000	85.55
TRON	26	1.26	4,639,184,120	7.21
Binance Chain	83	4.02	2,297,032,000	3.57
Omni	3	0.15	1,407,629,950	2.19
NEO	25	1.21	160,789,200	0.25
XRP	1	0.05	156,223,800	0.20
Stellar	21	1.02	155,640,200	0.24
EOS	31	1.50	117,560,200	0.18
Qtum	8	0.39	71,898,580	0.11
RSK Smart Bitcoin	1	0.05	70,715,650	0.11
Others	75	3.63	227,652,769	0.35

SOURCE: coinmarketcap.com and tether.to as of September 3, 2020. Data preparation is in the style of Roth, Schär, and Schöpfer (2019).

and on-chain asset management. This allows us to establish the foundation needed for our analysis of the potential and risks of DeFi.²

2.1 Asset Tokenization

Public blockchains are databases that allow participants to establish a shared and immutable record of ownership—a ledger. Usually, a ledger is used to track the native protocol asset of the respective blockchain. However, when public blockchain technology became more popular, so did the idea of making additional assets available on these ledgers. The process of adding new assets to a blockchain is called tokenization, and the blockchain representation of the asset is referred to as a token.

The general idea of tokenization is to make assets more accessible and transactions more efficient. In particular, tokenized assets can be transferred easily and within seconds from and to anyone in the world. They can be used in many decentralized applications and stored within smart contracts. As such, these tokens are an essential part of the DeFi ecosystem.

From a technological perspective, there are various ways in which public blockchain tokens can be created (see Roth, Schär, and Schöpfer, 2019). However, most of these options can be ignored, as the vast majority of tokens are issued on the Ethereum blockchain through a smart contract template referred to as the ERC-20 token standard (Vogelsteller and Buterin, 2015). These tokens are interoperable and can be used in almost all DeFi applications. As of January 2021, there are over 350,000 ERC-20 token contracts deployed on Ethereum.³ Table 1 shows the number of tokens listed on exchanges and the aggregated token market cap in USD per

blockchain. Almost 90 percent of all listed tokens are issued on the Ethereum blockchain. The slight deviation in terms of market cap originates from the fact that a relatively large portion of the USDT stablecoin has been issued on Omni.

From an economic perspective, I am more interested in the asset's nature than in the underlying technical standard used to implement the asset's digital representation. The main motivation for adding additional assets on-chain is the addition of a stablecoin. While it would be possible to use the aforementioned protocol assets (BTC or ETH), many financial contracts require a low-volatility asset. Tokenization enables the creation of these assets.

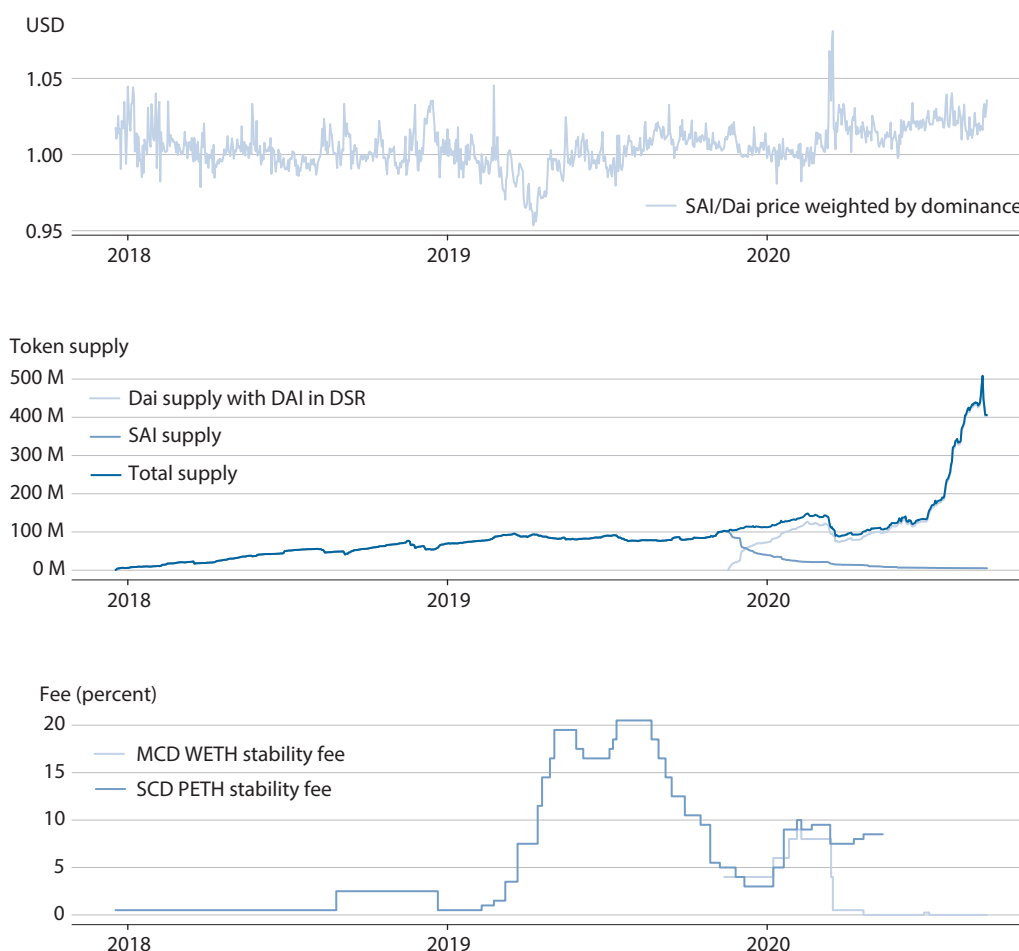
However, one of the main concerns with tokenized assets is issuer risk. Native digital tokens, such as BTC and ETH, are unproblematic in this regard. In contrast, when someone introduces tokens with a promise, for example, interest payments, dividends, or the delivery of a good or service, the corresponding token's value will depend on this claim's credibility. If an issuer is unwilling or unable to deliver, the token may become worthless or trade at a significant discount. This logic also applies to stablecoins.

Generally speaking, there are three backing models for promise-based tokens: *off-chain collateral*, *on-chain collateral*, and *no collateral*. Off-chain collateral means that the underlying assets are stored with an escrow service, for example, a commercial bank. On-chain collateral means that the assets are locked on the blockchain, usually within a smart contract.⁴ When there is no collateral, counterparty risk is at its highest. In this case, the promise is entirely trust-based. Berentsen and Schär (2019) have analyzed the three categories in the context of stablecoins.

On-chain collateral has several advantages. It is highly transparent, and claims can be secured by smart contracts, allowing processes to be executed in a semi-automatic way. A disadvantage of on-chain collateral is that this collateral is usually held in a native protocol asset (or a derivative thereof) and, therefore, will experience price fluctuations. Take the example of the Dai stablecoin, which mainly uses ETH as its on-chain collateral to create a decentralized and trustless Dai token pegged to the value of 1 USD. Since there is no native USD-pegged token on Ethereum, Dai tokens must be backed by another asset. Whenever anyone wants to issue new Dai tokens, they first need to lock enough ETH as underlying collateral in a smart contract provided by the Maker Protocol. Since the USD/ETH exchange rate is not fixed, there is a need for over-collateralization. If the value of the underlying ETH collateral at any point falls below the minimum threshold of 150 percent of the outstanding Dai value, the smart contract will auction off the collateral to cancel the debt in Dai.

Figure 3 shows some key metrics of the Dai stablecoin, including price, total Dai in circulation, and the stability fee, that is, the interest rate that has to be paid by anyone who is creating new Dai (see Section 2.3).

There are also several examples of off-chain collateralized stablecoins. The most popular ones are USDT and USDC, both USD-backed stablecoins. They are both available as ERC-20 tokens on the Ethereum blockchain. DGX is an ERC-20-based stablecoin backed by gold, and WBTC is a tokenized version of Bitcoin, making Bitcoin available on the Ethereum blockchain. Off-chain collateralized tokens can mitigate exchange rate risk, as the collateral may be equivalent to the tokenized claim (e.g., USD claim, backed by real USD). However, off-chain collateral-

Figure 3**Dai Stablecoin Key Metrics**

NOTE: M, million; SAI, (discontinued) single collateral stablecoin; DSR, Dai savings rate; MCD, multi-collateral Dai stablecoin backed by ETH; SCD, single collateral Dai stablecoin backed by ETH; MCD WETH stability fee, MCD stablecoin interest rate in ETH; SCD PETH stability fee, SCD stablecoin interest rate in ETH.

SOURCE: DeFi Pulse and CoinMarketCap.

alized tokens introduce counterparty risk and external dependencies. Tokens that use off-chain collateral require regular audits and precautionary measures to ensure that the underlying collateral is available at all times. This process is costly and, in many cases, not entirely transparent for the token holders.

While I am unaware of any functional designs for unbacked stablecoins, that is, stablecoins that do not use any form of collateral to maintain the peg, several organizations are working on that idea. Note that rebase tokens such as Ampleforth or YAM do not qualify as stablecoins. They only provide a stable unit of account but still expose the holder to volatility in the form of a dynamic token quantity.

Although stablecoins serve a vital role in the DeFi ecosystem, it would not do justice to the subject of tokenization to limit the discussion to these assets. There are all kinds of tokens that serve a variety of purposes, including governance tokens for decentralized autonomous organizations (DAO), tokens that allow the holder to perform specific actions in a smart contract, tokens that resemble shares or bonds, and even synthetic tokens that can track the price of any real-world asset.

Another distinct category are so-called non-fungible tokens (NFTs). NFTs are tokens that represent unique assets, that is, collectibles. They can either be the digital representation of a physical object such as a piece of art, making them subject to the usual counterparty risk, or a digitally native unit of value with unique characteristics. In any case, the token's non-fungibility attributes ensure that the ownership of each asset can be individually tracked and the asset precisely identified. NFTs usually are built on the ERC-721 token standard (Entriken et al., 2018).

The following sections discuss the protocol layer and examine how tokens can be traded using decentralized exchanges (Section 2.2), how they can be used as collateral for loans (Section 2.3) and to create decentralized derivatives (Section 2.4), and how they can be included in on-chain investment funds (Section 2.5).

2.2 Decentralized Exchange Protocols

As of September 2020, there are over 7,092 cryptoassets⁵ listed on exchanges. While most of them are economically irrelevant and have a negligible market cap and trading volume, there is a need for marketplaces where people can trade the more popular ones. This would allow owners of such assets to rebalance their exposure according to their preferences and risk profiles and adjust portfolio allocations.

In most cases, cryptoasset trades are conducted through centralized exchanges. Centralized exchanges are relatively efficient, but they have one severe problem. To be able to trade on a centralized exchange, traders must first deposit assets with the exchange. They thereby forfeit direct access to their assets and have to trust the exchange operator. Dishonest or unprofessional exchange operators may confiscate or lose assets. Moreover, centralized exchanges create a single point of attack and face the constant threat of becoming the target of malicious third parties. The relatively low regulatory scrutiny intensifies both problems and the immense scaling efforts many of these exchanges had to go through within a short time. Accordingly, it is no surprise that some centralized cryptoasset exchanges have lost customer funds.

Decentralized exchange protocols try to mitigate these issues by removing the trust requirement. Users no longer must deposit their funds with a centralized exchange. Instead, they remain in exclusive control of their assets until the trade is executed. Trade execution happens atomically through a smart contract, meaning that both sides of the trade are performed in one indivisible transaction, mitigating the counterparty credit risk. Depending on the exact implementation, the smart contract may assume additional roles, effectively making many intermediaries such as escrow services and central counterparty clearing houses (CCPs) obsolete.

Early decentralized exchanges such as EtherDelta have been set up as walled gardens with no interaction between the various implementations. The exchanges had no shared liquidity,

Table 2**Most Popular Decentralized Exchange Protocols**

Protocol name	Protocol type	Price discovery
0x	Exchange	Off-chain order books
(Air)Swap	P2P / OTC	P2P negotiation
Bancor	CFMM	Smart contract
Balancer	CFMM	Smart contract
Curve	CFMM	Smart contract
Kyber Network	Reserve aggregator	Proposal by maker
UniSwap	CFMM	Smart contract

NOTE: CFMM, constant function market maker.

leading to relatively low transaction volumes and large bid/ask spreads. High network fees, as well as cumbersome and slow processes to move funds between these decentralized exchanges, have rendered supposed arbitrage opportunities useless.

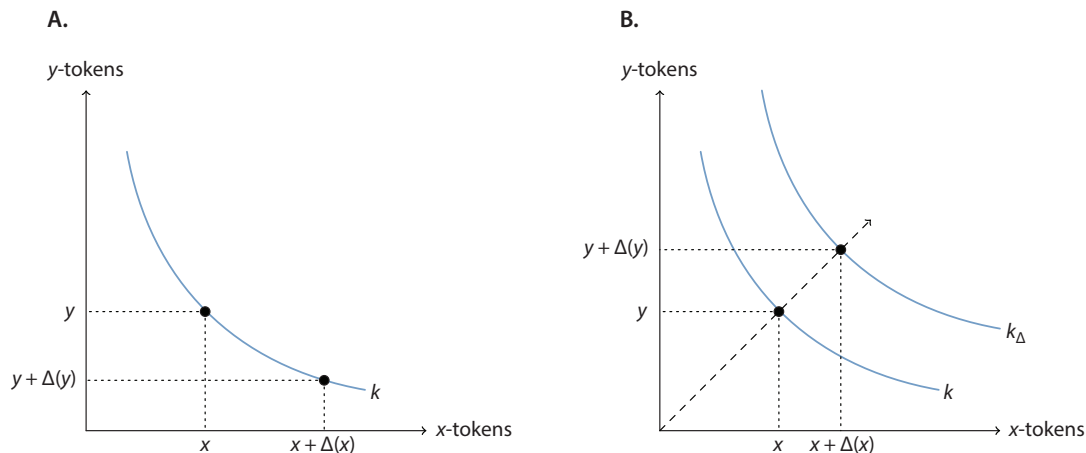
More recently, there has been a move toward open exchange protocols. These projects try to streamline the architecture of decentralized exchanges by providing standards on how asset exchange can be conducted and allowing any exchange built on top of the protocol to use shared liquidity pools and other protocol features. However, most importantly, other DeFi protocols can use these marketplaces and exchange or liquidate tokens when needed.

In the following subsections, I compare various types of decentralized exchange protocols, some of which are not exchanges in the narrow sense but have been included in the analysis, as they serve the same purpose. The results are summarized in Table 2.

Decentralized Order Book Exchanges. Decentralized order book exchanges can be implemented in a variety of ways. They all use smart contracts for transaction settlement, but they differ significantly in how the order books are hosted. One has to distinguish between on-chain and off-chain order books.

On-chain order books have the advantage of being entirely decentralized. Every order is stored within the smart contract. As such, there is no need for additional infrastructure or third-party hosts. The disadvantage of this approach is that every action requires a blockchain transaction. Therefore, it is a costly and slow process for which even the declaration of the intent to trade results in network fees. Considering that volatile markets will require frequent order cancellations, this disadvantage becomes even more costly.

For this reason, many decentralized exchange protocols rely on off-chain order books and only use the blockchain as a settlement layer. Off-chain order books are hosted and updated by centralized third parties, usually referred to as relayers. They provide takers with the information they need to select an order they would like to match. While this approach indeed introduces some centralized components and dependencies to the system, the relayers' role is limited. Relayers are never in control of the funds and neither match nor execute the orders.

Figure 4**Visualization of Liquidity Pool Token Reserves in a Constant Product Model**

They simply provide ordered lists with quotes and may charge a fee for that service. The openness of the protocol ensures that there is competition among the relayers and mitigates potential dependencies.

The dominant protocol that uses this approach is called 0x (Warren and Bandelei, 2017). The protocol uses a three-step process for trades. First, the maker sends a pre-signed order to the relayer for inclusion in the order book. Second, a potential taker queries the relayer and selects one of the orders. Third, the taker signs and submits the order to the smart contract, triggering the atomic exchange of the cryptoassets.

Constant Function Market Maker. A constant function market maker (CFMM) is a smart contract-liquidity pool that holds (at least) two cryptoassets in reserve and allows anyone to deposit tokens of one type and thereby to withdraw tokens of the other type. To determine the exchange rate, smart contract-based liquidity pools use variations of the constant product model, where the relative price is a function of the smart contract's token reserve ratio. The earliest implementation I am aware of was proposed by Hertzog, Benartzi, and Benartzi (2017). Adams (2018) has simplified the model, and Zhang, Chen, and Park (2018) provide a formal proof of the concept. Martinelli and Mushegian (2019) generalized the concept for cases with more than two tokens and dynamic token weights. Egorov (2019) optimized the idea for stablecoin swaps.

In its simplest form, the constant product model can be expressed as $xy = k$, where x and y correspond to the smart contract's token reserves and k is a constant. Considering that this equation must hold, when someone executes a trade, we get $(x + \Delta x) \cdot (y + \Delta y) = k$. It can then be easily shown that $\Delta y = (k/(x + \Delta x)) - y$. Consequently, Δy will assume negative values for any $\Delta x > 0$. In fact, any exchange corresponds to a move on a convex token reserve curve, which is shown in Figure 4A. A liquidity pool using this model cannot be depleted, as tokens will

get more expensive with lower reserves. When the token supply of either one of the two tokens approaches zero, its relative price rises infinitely as a result.

It is important to point out that smart contract-based liquidity pools are not reliant on external price feeds (so-called oracles). Whenever the market price of an asset shifts, anyone can use the arbitrage opportunity and trade tokens with the smart contract until the liquidity pool price converges to the current market price. The implicit bid/ask spread of the constant product model (plus a small trading fee) may lead to the accumulation of additional funds. Anyone who provides liquidity to the pool receives pool share tokens that allow them to participate in this accumulation and to redeem these tokens for their share of a potentially growing liquidity pool. Liquidity provision results in a growing k and is visualized in Figure 4B.

Prominent examples of smart contract-based liquidity pool protocols are UniSwap, Balancer, Curve, and Bancor.

Smart Contract-Based Reserve Aggregation. Another approach is to consolidate liquidity reserves through a smart contract that allows large liquidity providers to connect and advertise prices for specific trade pairs. A user who wants to exchange token x for token y may send a trade request to the smart contract. The smart contract will compare prices from all liquidity providers, accept the best offer on behalf of the user, and execute the trade. It acts as a gateway between users and liquidity providers, ensuring best execution and atomic settlement.

In contrast to smart contract-based liquidity pools, with smart contract-based reserve aggregation, prices are not determined within the smart contract. Instead, prices are set by the liquidity providers. This approach works fine if there is a relatively broad base of liquidity providers. However, if there is limited or no competition for a given trade pair, the approach may result in collusion risks or even monopolistic price setting. As a countermeasure, reserve aggregation protocols usually have some (centralized) control mechanisms, such as maximum prices or a minimum number of liquidity providers. In some cases, liquidity providers may only participate after a background check, including KYC (know your customer) verification.

The best-known implementation of this concept is the Kyber Network (Luu and Velner, 2017), which serves as a backbone protocol for a large variety of DeFi applications.

Peer-to-Peer Protocols. An alternative to classic exchange or liquidity pool models are peer-to-peer (P2P) protocols, also called over-the-counter (OTC) protocols. They mostly rely on a two-step approach, where participants can query the network for counterparties who would like to trade a given pair of cryptoassets and then negotiate the exchange rate bilaterally. Once the two parties agree on a price, the trade is executed on-chain via a smart contract. In contrast to other protocols, offers can be accepted exclusively by the parties who have been involved in the negotiation. In particular, it is not possible for a third party to front-run someone accepting an offer by observing the pool of unconfirmed transactions (mempool).

To make things more efficient, the process is usually automated. Additionally, one can use off-chain indexers for peer discovery. These indexers assume the role of a directory in which people can advertise their intent to make a specific trade. Note that these indexers only serve to establish a connection. Prices are still negotiated P2P.

AirSwap is the most popular implementation of a decentralized P2P protocol. It was proposed by Oved and Mosites (2017).

2.3 Decentralized Lending Platforms

Loans are an essential part of the DeFi ecosystem. There are a large variety of protocols that allow people to lend and borrow cryptoassets. Decentralized loan platforms are unique in the sense that they require neither the borrower nor the lender to identify themselves. Everyone has access to the platform and can potentially borrow money or provide liquidity to earn interest. As such, DeFi loans are completely permissionless and not reliant on trusted relationships.

To protect the lender and stop the borrower from running away with the funds, there are two distinct approaches: First, credit can be provided under the condition that the loan must be repaid atomically, meaning that the borrower receives the funds, uses, and repays them—all within the same blockchain transaction. Suppose the borrower has not returned the funds (plus interest) at the end of the transaction's execution cycle. In this case, the transaction will be invalid and any of its results (including the loan itself) reverted. These so-called flash loans (Wolff, 2018; Boado, 2020) are an exciting but still highly experimental application. While flash loans can only be employed in applications that are settled atomically and entirely on-chain, they are an efficient new instrument for arbitrage and portfolio restructuring. As such, they are on track to become an essential part of DeFi lending.

Second, loans can be fully secured with collateral. The collateral is locked in a smart contract and only released once the debt is repaid. Collateralized loan platforms exist in three variations: *Collateralized debt positions*, *pooled collateralized debt markets*, and *P2P collateralized debt markets*. Collateralized debt positions are loans that use newly created tokens, while debt markets use existing tokens and require a match between a borrowing and a lending party. The three variations are discussed below.

Collateralized Debt Positions. Some DeFi applications allow users to create collateralized debt positions and thereby issue new tokens that are backed by the collateral. To be able to create these tokens, the person must lock cryptoassets in a smart contract. The number of tokens that can be created depends on the target price of the tokens generated, the value of the cryptoassets that are being used as collateral, and the target collateralization ratio. The newly created tokens are essentially fully collateralized loans that do not require a counterparty and allow the user to get a liquid asset while maintaining market exposure through the collateral. The loan can be used for consumption, allowing the person to overcome a temporary liquidity squeeze or to acquire additional cryptoassets for leveraged exposure.

To illustrate the concept, let us use the example of MakerDAO, a decentralized protocol that is used to issue the USD-pegged Dai stablecoin. First, the user deposits ETH in a smart contract classified as a collateralized debt position (CDP) (or vault). Subsequently, they call a contract function to create and withdraw a certain number of Dai and thereby lock the collateral. This process currently requires a minimum collateralization ratio of 150 percent, meaning that for any 100 USD of ETH locked up in the contract, the user can create at most 66.66 Dai.⁶

Any outstanding Dai is subject to a stability fee, which in theory should correspond to the Dai debt market's maximum interest rate. This rate is set by the community, namely the

MKR token holders. MKR is the governance token for the MakerDAO project. As shown in Figure 3, the stability fee has been fluctuating wildly between 0 and 20 percent.

To close a CDP, the owner must send the outstanding Dai plus the accumulated interest to the contract. The smart contract will allow the owner to withdraw their collateral once the debt is repaid. If the borrower fails to repay the debt, or if the collateral's value falls below the 150 percent threshold, where the full collateralization of the loan is at risk, the smart contract will start to liquidate the collateral at a potentially discounted rate.

Interest payments and liquidation fees are partially used to “burn” MKR, thereby decreasing the total MKR supply. In exchange, MKR holders assume the residual risk of extreme negative ETH price shocks, which may lead to a situation in which the collateral is insufficient to maintain the USD peg. In this case, new MKR will be created and sold at a discounted rate. As such, MKR holders have skin in the game, and it should be in their best interest to maintain a healthy system.

It is important to mention that the MakerDAO system is much more complicated than what is described here. Although the system is mostly decentralized, it is reliant on price oracles, which introduce some dependencies, as discussed in Section 3.2.

MakerDAO has recently switched to a multi-collateral system, with the goal to make the protocol more scalable by allowing a variety of cryptoassets to be used as collateral.

Collateralized Debt Markets. Instead of creating new tokens, it is also possible to borrow existing cryptoassets from someone else. For obvious reasons, this approach requires a counterparty with opposing preferences. In other words: For someone to be able to borrow ETH, there must be another person willing to lend ETH. To mitigate counterparty risk and protect the lender, loans must be fully collateralized, and the collateral is locked in a smart contract—just as in our previous example.

Matching lenders with borrowers can be done in a variety of ways. The broad categories are P2P and pooled matching. P2P matching means that the person who is providing the liquidity lends the cryptoassets to specific borrowers. Consequently, the lender will only start to earn interest once there is a match. The advantage of this approach is that the parties agree on a time period and operate with fixed interest rates.

Pooled loans use variable interest rates that are subject to supply and demand. The funds of all borrowers are aggregated in a single, smart contract-based lending pool, and lenders start to earn interest right when they deposit their funds in the pool. However, the interest rates are a function of the pool's utilization rate. When liquidity is readily available, loans will be cheap. When it is in great demand, loans will become more expensive. Lending pools have the additional advantage that they can perform maturity and size transformation while maintaining relatively high liquidity for the individual lender.

There is a large variety of lending protocols. Some of the most popular ones are Aave (Boado, 2020), Compound (Leshner and Hayes, 2019), and dYdX (Juliano, 2017). Figure 5 shows the asset-weighted borrowing and lending rates for Dai and ETH. For Dai, the figure also includes the MakerDAO stability fee, which should always be the highest rate in the system. Surprisingly, this is not always the case, meaning that some people have paid a price premium

Figure 5**Weighted Dai Collateralized Debt Market Rates and the MakerDAO Stability Fee**

SOURCE: DeFi Pulse.

in the secondary market. As of September 2020, Dai accounts for almost 75 percent of all loans in the DeFi ecosystem.

2.4 Decentralized Derivatives

Decentralized derivatives are tokens that derive their value from an underlying asset's performance, the outcome of an event, or the development of any other observable variable. They usually require an oracle to track these variables and therefore introduce some dependencies and centralized components. The dependencies can be reduced when the derivative contract uses multiple independent data sources.

We differentiate between asset-based and event-based derivative tokens. We call a derivative token asset-based when its price is a function of an underlying asset's performance. We call a derivative event-based when its price is a function of any observable variable that is not the performance of an asset. Both categories will be discussed in the following sections.

Asset-Based Derivative Tokens. Asset-based derivative tokens are an extension of the CDP model described in Section 2.3. Instead of limiting the issuance to USD-pegged stablecoins, the locked collateral can be used to issue synthetic tokens that follow the price movements of a variety of assets. Examples include tokenized versions of stocks, precious metals, and alternative cryptoassets. The higher the underlying volatility, the larger the risk of falling below a given collateralization ratio.

A popular derivative token platform is called Synthetix (Brooks et al., 2018). It is implemented so that the total debt pool of all participants increases or decreases depending on the aggregate price of all outstanding synthetic assets. This ensures that tokens with the same underlying assets remain fungible; that is, redemption does not depend on the issuer. The flip side of this design is that users assume additional risk when they mint assets, as their debt position will also be affected by everyone else's asset allocation.

A particular case of asset-based derivative tokens are inverse tokens. Here, the price is determined by an inverse function of the underlying assets' performance within a given price range. These inverse tokens allow users to get short exposure to cryptoassets.

Event-Based Derivative Tokens. Event-based derivative tokens can be based on any objectively observable variable with a known set of potential outcomes, a specified observation time, and a resolution source.² Anyone can buy a full set of sub-tokens for a given event by locking 1 ETH in a smart contract. A complete set of sub-tokens consists of 1 sub-token for each potential outcome. These sub-tokens can be traded individually. When the market resolves, the smart contract's cryptoassets will be split among the sub-token owners of the winning outcome. In the absence of market distortions, each sub-token's ETH price should, therefore, correspond to the probability of the underlying outcome.

Under certain circumstances, these prediction markets may serve as decentralized oracles for the likelihood of a future outcome. However, market resolution (and therefore the price) greatly depends on the trustworthiness of the resolution source. As such, event-based derivative tokens introduce external dependencies and may be unilaterally influenced by a malicious reporter. Potential attack vectors include flawed or misleading question specifications, incomplete outcome sets that may render the event unresolvable, and the choice of unreliable or fraudulent resolution sources.

The most popular implementation is called Augur (Peterson et al., 2019). It uses a multi-stage resolution and disputing process that should minimize the dependency on a single reporting source as much as possible. If the token holders do not agree with the designated reporter, they may start a dispute, which should eventually lead to the correct outcome.

2.5 On-Chain Asset Management

Just like traditional investment funds, on-chain funds are mainly used for portfolio diversification. They allow users to invest in a basket of cryptoassets and employ a variety of strategies without having to handle the tokens individually. In contrast to traditional funds, the on-chain variant does not require a custodian. Instead, the cryptoassets are locked up in a smart contract. The investors never lose control over their funds, can withdraw or liquidate them, and can observe the smart contracts' token balances at any point in time.

The smart contracts are set up in such a way that they follow a variety of simple strategies, including semi-automatic rebalancing of portfolio weights and trend trading, using moving averages. Alternatively, one or multiple fund managers can be selected to manage the fund actively. In this case, the smart contract ensures that asset managers adhere to the predefined strategy and act in the investors' best interest. In particular, asset managers are limited to actions in accordance with the fund's ruleset and the risk profile stipulated in the smart contract. The smart contract can mitigate many forms of the principal-agent problem and incorporate regulatory requirements by enforcing them on-chain. As a result, on-chain asset management may lead to lower fund setup and auditing costs.

Whenever someone invests in an on-chain fund, the corresponding smart contract issues *fund tokens* and transfers them to the investor's account. These tokens represent partial

ownership of the fund and allow token holders to redeem or liquidate their share of the assets. For example, if an investor owns 1 percent of the fund tokens, this person would be entitled to 1 percent of the locked cryptoassets. When the investor decides to close out the investment, the fund tokens get burned, the underlying assets are sold on a decentralized exchange, and the investor is compensated with the ETH-equivalent of their share of the basket.

There are several implementations of on-chain fund protocols, including the Set Protocol (Feng and Weickmann, 2019), Enzyme Finance (formerly Melon) (Trinkler and El Isa, 2017), Yearn Vaults (Cronje, 2020), and Betoken (Liu and Palayer, 2018). All of these implementations are limited to ERC-20 tokens and Ether. Moreover, they heavily depend on price oracles and third-party protocols, mainly for lending, trading, and the inclusion of low-volatility reference assets such as the Dai or USDC stablecoins. Consequently, there are severe dependencies, which will be discussed in Section 3.2.

Both Enzyme Finance and Set Protocol allow anyone to create new investment funds. Enzyme Finance has a focus on building an infrastructure for decentralized funds, using smart contract-based rulesets to ensure that fund managers stick to the funds' strategies. Trading restriction parameters such as maximum concentration, price tolerance, and the maximum number of positions, as well as user and asset whitelists and blacklists, are enforced by these smart contracts. The same is true for the fund's fee schedule. Set Protocol is mainly designed for semi-automated strategies with deterministic portfolio rebalancing triggered by predefined threshold values and timelocks. However, the protocol is also used for active management. Betoken operates as a single fund of funds managed by a community of asset managers through a meritocratic system. The more successful an individual fund manager is, the greater their future influence on allocating the collective resources. UniSwap's liquidity pool (see Section 2.2) also has some characteristics of an on-chain investment fund. The constant product model creates the incentives for a semi-automatic rebalancing of portfolio weights, while the trading fees generate passive income for the investors.

Yearn Vaults are collective investment pools designed to maximize yield for a given asset. Strategies are quite diverse but usually involve several steps and active management. In many cases, these actions would be too expensive (in terms of transaction fees) for smaller amounts. Moreover, they require that the investor is vigilant and well-informed. Yearn Vaults mitigate these issues by employing the knowledge of the masses and using collective action to split network fees proportionally among all participants. However, the deep integration of the protocol also introduces severe dependencies.

3 OPPORTUNITIES & RISKS

In this section, we analyze the opportunities and risks of the DeFi ecosystem. It lays the foundation for the discussion in Section 4.

3.1 Opportunities

DeFi may increase the *efficiency*, *transparency*, and *accessibility* of the financial infrastructure. Moreover, the system's *composability* allows anyone to combine multiple applications

and protocols, thereby creating new and exciting services. We discuss these aspects in the following subsections.

Efficiency. While much of the traditional financial system is trust based and dependent on centralized institutions, DeFi replaces some of these trust requirements with smart contracts. The contracts can assume the roles of custodians, escrow agents, and CCPs. For example, if two parties want to exchange digital assets in the form of tokens, there is no need for guarantees from a CCP. Instead, the two transactions can be settled atomically, meaning that either both or neither of the transfers will be executed. This significantly decreases counterparty credit risk and makes financial transactions much more efficient. Lower trust requirements may come with the additional benefit of reducing regulatory pressure and reducing the need for third-party audits. Similar efficiency gains are possible for almost every area of the financial infrastructure.

Additionally, token transfers are much faster than any of the transfers in the traditional financial system. Transfer speed and transaction throughput can be further increased with Layer 2 solutions, such as sidechains or state- and payment-channel networks.

Transparency. DeFi applications are transparent. All transactions are publicly observable, and the smart contract code can be analyzed on-chain. The observability and deterministic execution allow—at least in theory—an unprecedented level of transparency.

Financial data are publicly available and may potentially be used by researchers and users alike. In the case of a crisis, the availability of historical (and current) data is a vast improvement over traditional financial systems, where much of the information is scattered across a large number of proprietary databases or not available at all. As such, transparency of DeFi applications may allow for the mitigation of undesirable events before they arise and help provide much faster understanding of their origin and potential consequences when they emerge.

Accessibility. By default, DeFi protocols can be used by anyone. As such, DeFi may potentially create a genuinely open and accessible financial system. In particular, the infrastructure requirements are relatively low and the risk of discrimination is almost inexistent due to the lack of identities.

If regulation demands access restrictions, for example, for security tokens, such restrictions can be implemented in the token contracts without compromising the settlement layer's integrity and decentralization properties.

Composability. DeFi protocols are often compared with Lego pieces. The shared settlement layer allows these protocols and applications to interconnect. On-chain fund protocols can make use of decentralized exchange protocols or achieve leveraged positions through lending protocols.

Any two or more pieces can be integrated, forked, or rehashed to create something entirely new. Anything that has been created before can be used by an individual or by other smart contracts. This flexibility allows for an ever-expanding range of possibilities and unprecedented interest in open financial engineering.

3.2 Risks

DeFi also has certain risks, namely, *smart contract execution risk*, *operational security*, and *dependencies* on other protocols and external data. We discuss these aspects in the following subsections.

Smart Contract Execution. While the deterministic and decentralized execution of smart contracts does have its advantages, there is risk that something may go wrong. If there are coding errors, these errors may potentially create vulnerabilities that allow an attacker to drain the smart contract's funds, cause chaos, or render the protocol unusable. Users have to be aware that the protocol is only as secure as the smart contracts underlying it. Unfortunately, the average user will not be able to read the contract code, let alone evaluate its security. While audits, insurance services, and formal verification are partial solutions to this problem, some degree of uncertainty remains.

Similar risks exist in contract execution. Most users do not understand the data payload they are asked to sign as part of transactions and may be misled by a compromised front end. Unfortunately, there seems to be an inherent trade-off between usability and security. For example, some decentralized blockchain applications will ask for permissions to transfer an infinite number of tokens on behalf of the user—usually to make future transactions more convenient and efficient. Such permission, however, puts the user's funds at risk.

Operational Security. Many DeFi protocols and applications use admin keys. These keys allow a predefined group of individuals (usually the project's core team) to upgrade the contracts and to perform emergency shutdowns. While it is understandable that some projects want to implement these precautionary measures and remain somewhat flexible, the existence of these keys can be a potential problem. If the keyholders do not create or store their keys securely, malicious third parties could get their hands on these keys and compromise the smart contract. Alternatively, the core team members themselves may be malicious or corrupted by significant monetary incentives.

Most projects try to mitigate this risk with multisig and timelocks. Multisig requires *M*-of-*N* keys to execute any of the smart contract's admin functions, and timelocks specify the earliest time at which a transaction can be (successfully) confirmed.

As an alternative, some projects rely on voting schemes, where the respective governance tokens grant their owners the right to vote on the protocol's future. However, in many cases, the majority of governance tokens are held by a small group of people, effectively leading to similar results as with admin keys. Some projects have tried to mitigate this concentration of voting power by rewarding early adopters and users who fulfill specific criteria, which range from simple protocol usage to active participation in the voting process and third-party token staking (yield farming). Nevertheless, even when a launch is perceived as being relatively "fair," the actual distribution often remains highly concentrated.

Governance tokens may lead to undesirable consequences. In fact, a high concentration of power may be even more problematic when these rights are tokenized. In the absence of vesting periods, malicious founders can pull the rug by dumping their entire token holding on a CFMM, causing a massive supply shock and undermining the project's credibility. Moreover,

yield farming may lead to *centralization creep* by allowing an already well-established protocol to assume a significant portion of a relatively new protocol's governance tokens. This may create large meta protocols whose token holders essentially control a considerable portion of the DeFi infrastructure.

Dependencies. As described in Section 3.1, some of the most promising features of the DeFi ecosystem are its openness and composability. These features allow various smart contracts and decentralized blockchain applications to interact with each other and to offer new services based on a combination of existing ones. On the flip side, these interactions introduce severe dependencies. If there is an issue with one smart contract, it may potentially have wide-reaching consequences for multiple applications across the entire DeFi ecosystem. Moreover, problems with the Dai stablecoin or severe ETH price shocks may cause ripple effects throughout the whole DeFi ecosystem.

The problem becomes apparent when illustrated by an example. Let us assume that a person locks ETH as collateral in the MakerDAO contract to issue Dai stablecoins. Let us further assume that the Dai stablecoins are locked in a compound lending smart contract to issue interest-bearing derivative tokens, called cDai. The cDai tokens are subsequently moved to the UniSwap ETH/cDai liquidity pool, along with some ETH, allowing the person to withdraw UNI-cDai tokens representing a share of the liquidity pool. With every additional smart contract, the potential risk of a bug increases. If any of the contracts in the sequence fail, the UNI-cDai tokens could potentially become worthless. These “token on top of a token on top of a token” scenarios, which create wrapper tokens, can entangle projects in such a way that theoretical transparency does not correspond to actual transparency.

External Data. Another point worth mentioning is the fact that many smart contracts are reliant on external data. Whenever a smart contract depends on data that are not natively available on-chain, the data must be provided by external data sources. These so-called oracles introduce dependencies and may, in some cases, lead to heavily centralized contract execution. To mitigate this risk, many projects rely on decentralized oracle networks with a large variety of data provision schemes.

Illicit Activity. A common concern among regulators is that cryptoassets may be used by individuals who want to avoid records and monitoring. While the inherent transparency of DeFi is a deterrent to this use case, the network's pseudonymity may provide some privacy. However, this may not necessarily be a bad thing, and the situation is more complicated than it may seem at first glance. On the one hand, pseudonymity can be abused by actors with dishonest intentions. On the other hand, privacy may be a desirable attribute for some legitimate financial applications. Correspondingly, regulators should act with great care, trying to find reasonable solutions that allow them to step in where necessary without stifling innovation. Moreover, one has to be aware that regulating a decentralized network may not be feasible.

While it is questionable whether regulators can (or should) regulate a decentralized infrastructure, there are two areas that deserve special attention, namely, fiat on- and off-ramps and the decentralization theater.

Fiat on- and off-ramps are the interface to the traditional financial system. Whenever people want to move assets from their bank account to the blockchain-based system or the other way, they have to go through a financial service provider. These financial service providers are regulated and may require background checks on the origin of the funds.

In a similar vein, it is important to differentiate between legitimate decentralized protocols and projects that only claim to be decentralized but are in fact under the exclusive control of an organization or a few individuals. The former may provide exciting new possibilities and remove some dependencies, while the latter may essentially introduce the worst of two worlds, that is, de facto dependencies on a centralized operator with limited supervision. Keeping this in mind, regulators should watch closely and analyze carefully if a given DeFi protocol is indeed decentralized or if the DeFi label is just for show in an attempt to get around regulation.

Scalability. Blockchains face the ultimate trade-off between decentralization, security, and scalability. While the Ethereum blockchain is generally regarded as relatively decentralized and secure, it struggles to keep up with the great demand for block space. Escalating gas prices (transaction fees) and long confirmation times adversely affect the DeFi ecosystem and favor wealthy individuals who can conduct large trades.

Potential solutions to this problem include base-layer sharding, as well as various Layer 2 solutions, such as state channels, ZK (zero knowledge) rollups, and optimistic rollups. However, in many cases, scalability efforts weaken composability and general transaction atomicity—two of DeFi’s most prominent features. On the other hand, moving DeFi to a more centralized base layer does not seem to be a reasonable approach either, as it would essentially undermine its main value proposition. Thus, it remains to be seen if a truly decentralized blockchain can keep up with the demand and provide the foundation for an open, transparent, and immutable financial infrastructure.

4 CONCLUSION

DeFi offers exciting opportunities and has the potential to create a truly open, transparent, and immutable financial infrastructure. Because DeFi consists of numerous highly interoperable protocols and applications, every individual can verify all transactions and data is readily available for users and researchers to analyze.

DeFi has unleashed a wave of innovation. On the one hand, developers are using smart contracts and the decentralized settlement layer to create trustless versions of traditional financial instruments. On the other hand, they are creating entirely new financial instruments that could not be realized without the underlying public blockchain. *Atomic swaps*, *autonomous liquidity pools*, *decentralized stablecoins*, and *flash loans* are just a few of many examples that show the great potential of this ecosystem.

While this technology has great potential, there are certain risks involved. Smart contracts can have security issues that may allow for unintended usage, and scalability issues limit the number of users. Moreover, the term “decentralized” is deceptive in some cases. Many protocols and applications use external data sources and special admin keys to manage the system,

conduct smart contract upgrades, or even perform emergency shutdowns. While this does not necessarily constitute a problem, users should be aware that, in many cases, there is much trust involved. However, if these issues can be solved, DeFi may lead to a paradigm shift in the financial industry and potentially contribute toward a more robust, open, and transparent financial infrastructure. ■

NOTES

- ¹ An alternative approach can be found here: <https://medium.com/pov-crypto/ethereum-the-digital-finance-stack-4ba988c6c14b>.
- ² For readers who wish to understand the settlement layer better and want to read a general introduction to blockchain and cryptocurrencies, see Berentsen and Schär (2018).
- ³ Etherscan (2021).
- ⁴ UTXO-based blockchain implementations such as Bitcoin allow sophisticated unlocking conditions through their scripting language. Although most people would not call these locking scripts a smart contract, they achieve similar goals in terms of the blockchain's custodial capabilities.
- ⁵ CoinMarketCap (2019).
- ⁶ In practice, the collateralization must be much larger, as any credit position with collateralization below 150 percent is liquidated.
- ⁷ For example, such a token was created in regard to the outcome of the recent U.S. presidential election.

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Understanding the Gender Earnings Gap: Hours Worked, Occupational Sorting, and Labor Market Experience

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This article documents life-cycle gender differences in labor market outcomes using longitudinal data of a cohort of individuals from the National Longitudinal Survey of Youth 1979. As in other datasets, the gender earnings gap increases with age. We find that hours worked and labor market experience are the most substantial observable variables in explaining the gender pay gap. We also focus on patterns in occupational changes over the life cycle, as a large part of pay growth occurs when workers change jobs. We find that college-educated men, on average, move into occupations with higher task complexity. We further show that women are less likely to change occupations. Moreover, on average, pay grows when workers change occupations, but the growth is smaller for women. Finally, we discuss theories that are consistent with the patterns we document. (JEL J16, J24, J31)

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1 INTRODUCTION

The labor force participation of women has increased substantially since the 1960s. At the same time, the gender earnings gap has declined from about 40 percent in the late 1960s to less than 28 percent in the early 1990s and has stopped converging since.¹ Much of the gender earnings gap is explained by gender differences in labor force attachment and accumulated labor market experience. In particular, the gender earnings gap increases with age as the experience gap increases.² One explanation for the remaining gender earnings gap is that many jobs disproportionately reward working long hours.³ In many jobs, the pay is nonlinear in hours worked and penalizes workers who choose to work fewer hours. This reward structure tends to affect women of childbearing years disproportionately and also affects their occupational choices. Furthermore, in most occupations, the representation of women at the top-paying jobs is low—even if at lower levels there are many women.⁴

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This article documents the evolution of the gender earnings gap over the life cycle using data from a cohort of men and women from the National Longitudinal Survey of Youth 1979 (NLSY79). The pattern is similar to the one documented in other datasets: The gender pay gap increases with age. To understand the factors affecting this pattern, we explore the role of occupations, hours worked, and work experience accumulated with age in the observed gender earnings. While previous literature analyzed occupational and labor force participation patterns, we document not only those but also task assignments and changes in task assignments over the life cycle.⁵ Previous literature did not analyze the evolution of task assignments and their changes over the life cycle in the context of the gender pay gap. Changes in occupational tasks and occupations are typically important to understanding the wage growth of workers over the life cycle. Our dataset allows us to account for both detailed labor supply history and heterogeneity in test scores and education.

Over time, as the earnings gap increases, the gap in weekly hours worked grows as well. This gap in hours is one of the factors that contributes to the increase in the earnings gap. We then study how occupations change over the life cycle. In particular, we explore whether the increase in the earnings gap is due to changes in occupational assignments and the evolution of the type of tasks workers are assigned. We also examine whether the occupational gap increases with age.

We define occupations along a unidimensional axis, measuring each occupation's demand for complex cognitive tasks. We focus on changes in nonroutine task complexity because over the life cycle workers typically transition into occupations with more cognitive task complexity and fewer motor skills requirements, which cause wages to increase (see Yamaguchi, 2012, for task analysis for men). We follow Antonovics and Golan (2012), who show that this transition is an important source of the increase in wage dispersion among white men, and Golan, Sanders, and James (2019) and Golan and Sanders (2019), who show that the transition is also an important source of the increase in the racial pay gap over the life cycle for men. We document that occupation matches and their pattern over the life cycle vary by education. As expected, workers with a college degree are matched with occupations of higher complexity than workers without a college degree.

We find that among workers with a college degree, men and women start in similar occupations. Over the life cycle, men surpass women in terms of the complexity of tasks performed. Among workers without a college degree, women start in higher-ranked occupations than men. Over the life cycle, these women remain ahead of these men. Thus, unlike the racial gaps and the increasing wage gaps for men, occupational task complexity may not explain much of the earnings gap for workers without a college degree.

The gender gaps above can be partly driven by differences in the observable and unobservable characteristics of men and women. We now analyze the role of differences between men and women based on observable characteristics in our data. A substantial gap in earnings remains after controlling for labor market experience, hours, Armed Forces Qualification Test (AFQT) scores, education, and occupation. We quantify the contribution of the different factors to the pay gap using the Blinder-Oaxca decomposition. Whereas a small difference in the earnings gap is explained by the compositional effects of college-educated men and women,

the differences in hours and labor market experience account for the majority of the gender earnings gap for college- and noncollege-educated workers. Moreover, we find that in our sample, the increase in the earnings gap with age is associated with the increase in the labor market experience gap and the breaks in labor force participation for both college- and noncollege-educated workers.⁶ We discuss our findings in light of different explanations in the literature. The gaps in hours worked and as a result of experience accumulated may be a result of differences in preferences and roles that women play in caring for children. However, discrimination in the labor market and lack of opportunity and promotions may also lead to these choices. Gayle and Golan (2011) find evidence that while there are preference differences, discrimination plays an important role in the choices of hours worked and experience accumulated.

For college-educated women, we find that task complexity does not increase on average as much as it does for college-educated men (after the initial entry years).⁷ Job changes are an important factor contributing to wage growth over the life cycle. On average, workers' wages increase when they change jobs, regardless of whether they move to perform more- or less-complex tasks (see Antonovics and Golan, 2012). We first document that women change occupations less often than men do. We next document that wage growth is lower for women when they change occupations. We then discuss theories that are consistent with the patterns we document. In particular, we discuss human capital and learning and sorting models. One theory is that of learning by doing (e.g., Jovanovic and Nyarko, 1997): Workers learn how to perform tasks and accordingly move up the job ladder, causing wages to increase over time. A second theory is search frictions in the labor market: Workers may not always find the jobs that best suit their qualifications initially, but over time they search and change jobs when they find better matches for their skill set. Lastly, workers do not always know which type of job matches their skills best and they learn about their own skills with experience (e.g., Jovanovic, 1979; Miller, 1984; and Antonovics and Golan, 2012, among others). Working fewer hours can reduce the amount of both learning by doing and learning about one's skills and therefore slow down the sorting of women into jobs that better suit their skill sets (e.g., Taber and Venjlin, 2016, and Lise and Postel-Vinay, 2020). However, discrimination may also imply that women are less likely to receive attractive offers and, therefore, are less likely to switch jobs. Family considerations may also affect women's likelihood of changing jobs if it requires moving.

The article is organized as follows. Section 2 describes the data construction and necessary information about the sample. Section 3 documents the gender gaps in earnings, task assignments, and hours over the life cycle and discusses possible reasons for the patterns. Section 4 analyzes the role of observable differences in the gender pay gap. Section 5 documents job changes and discusses theories consistent with the patterns. Section 6 concludes.

2 DATA

Our sample contains weekly panel data on U.S. birth cohorts for 1957-64 from the NLSY79. In particular, our base sample uses the 2,477 white females and 2,439 white males from the cross-sectional sample. From the NLSY79, we use histories on wages, hours worked,

three-digit job codes (the most disaggregated category from the 1970 Census coding system), level of education, age, gender, and AFQT scores.⁸

Although the NLSY79 contains information on individuals' labor force activities for each week from 1978 through the most recent year in which a respondent was interviewed, we rely only on labor market data from 1978 through 2000 because of a switch in job coding that occurred after 2000. If a person is not interviewed in a given year (or years), then at the next interview date, the respondent is asked to go back and retrospectively report their labor force activities. As a result, the NLSY allows us to construct relatively complete work histories. The work history data include information on each of up to five jobs a respondent may have held in a given week. We define a person's job in a given week to be the job at which they worked the most number of hours, but we still report our variables as the sum of the values of all jobs held in a given week. We begin each person's history in the week they begin employment after completing their highest degree. We end each person's history at 780 weeks of potential experience because attrition from the sample makes it difficult to construct complete work histories for longer horizons.

Using hours worked per week, we construct weeks of part-time experience and weeks of full-time experience. We count weeks of part-time experience as all the weeks that hours worked per week < 35. If hours worked per week are ≥ 35 , the week is counted as full-time experience.⁹

Using the person's main job each week, we match the job with Antonovics and Golan's (2012) " α " index for complex task assignments at each job. To construct this task assignment index, Antonovics and Golan (2012) use the *Dictionary of Occupational Titles* (DOT) (U.S. Census Bureau, 1981), which has information on the primary tasks done in a given job and the worker qualities needed for job success. The job qualities given in the DOT are linked to the 1970 Census three-digit job codes in an augmented version of the April 1971 Current Population Survey.¹⁰ The DOT is both comprehensive (describing 12,099 jobs) and detailed (along 44 dimensions). Antonovics and Golan (2012) run principal component analysis on the high-dimensional set of job measurements and take the first principal component, which seems to correspond to tasks that are nonroutine or complex, which are classified as jobs that require more skills that are hard to observe. They then construct their measure of α , normalized by calculating its percentile ranking and dividing by 100. This normalized predicted score takes on a value from 0.01 to 1.00. Higher values reflect more skills required. The α index is then matched to the job data from the NLSY79.

We take as our initial sample the cross-sectional sample of 4,916: 2,439 white males and 2,417 white females. We drop 887 respondents because we cannot identify either their highest degree or the date at which they received their highest degree; 653 respondents who completed their highest degree prior to the start date of the work history record; and 534 respondents who completed their highest degree relatively late in life, because we worry that these workers already may have accumulated substantial labor market experience that could influence employer's beliefs about skills. We also drop 52 respondents for whom we could not identify the start of their full-time employment and 326 respondents who had ever reported an hourly wage of either over \$200 or under \$2. We additionally drop 276 respondents for whom the worker history is relatively incomplete—in particular, respondents with more than 300 weeks

Table 1**Sample Means and Differences**

	Variable	Men	Women	% Δ	<i>p</i> -value Δ
Pre-labor market	AFQT score (raw)	61	61	0	0.999
	AFQT score (normal)	37	41	11	0.099*
First job	Age	21	21	0	0.251
	Wage (\$/hr)	11	10	-11	0.000***
	Earnings (\$/mo)	1,815	1,428	-21	0.000***
	Full time (%)	80	69	-14	0.000***
	α ($\times 100$)	46	51	11	0.000***
Current job	Age	28	28	0	0.244
	Wage (\$/hr)	17	14	-19	0.000***
	Earnings (\$/mo)	3,065	2,089	-32	0.000***
	Labor (hrs/wk)	42	34	-20	0.000***
	Labor (hrs/mo)	176	149	-16	0.000***
	α ($\times 100$)	55	60	9	0.000***
Experience	Part time (wks)	23	63	179	0.000***
	Full time (wks)	323	268	-17	0.000***
	Job spells	12.0	11	-7	0.003**
<i>N</i>		1,187	1,001	-16	

in which they did not work or with missing work information during the first 600 weeks following their transition to full-time work; that is, we give respondents 600 weeks in which to accumulate 300 weeks of valid work information, otherwise we drop them from the sample. After these drops, we are left with 2,188 individuals: 1,001 females and 1,187 males. Relative to the initial sample, these workers are young and have strong attachment to the labor force.

2.1 Summary Statistics

Table 1 provides summary statistics. On average, women's monthly earnings are 68 percent of men's. About 41 percent of women have a college degree or more, compared with 37 percent of men. Average monthly hours are 16 percent lower for women, and women accumulate on average 41 more weeks of part-time experience and 54 fewer weeks of full-time experience than men. Women enter the labor market with wages that are on average 11 percent lower than men's. Those differences persist and compound over the life cycle: Women's wages are on average 19 percent lower than men's. Women are 53 percent more likely to enter the labor market as a part-time worker. They are slightly older than men by 7.5 weeks, which is expected from their college attainment gap (8.6 percent, or 3.5 percentage points) multiplied by a standard four-year college education.

Table 2

Sample Means and Differences, College Degree

	Variable	Men	Women	% Δ	<i>p</i> -value
Pre-labor market	AFQT score (raw)	80	77	-4	0.023**
	AFQT score (normal)	0.7	0.6	-15	0.023**
First job	Age	24.0	24.0	0	0.879
	Wage (\$/hr)	14.25	12.70	-11	0.010***
	Earnings (\$/mo)	2,359	1,914	-19	0.000***
	Full time (%)	86	77	-10	0.001***
	α ($\times 100$)	67	66	-1	0.755
Current job	Age	30.9	30.8	0	0.635
	Wage (\$/hr)	23.29	18.54	-20	0.000***
	Earnings (\$/mo)	4,190	2,768	-34	0.000***
	Labor (hrs/wk)	44	35	-21	0.000***
	Labor (hrs/mo)	180	151	-16	0.000***
	α ($\times 100$)	75	74	-1	0.213
Experience	Part time (wks)	13	55	312	0.000***
	Full time (wks)	327	271	-17	0.000***
	Job spells	9	9	2	0.497
	<i>N</i>	444	409	-35	-8

We construct quintiles for α by assigning those with $\alpha \in [0.01, 0.2]$ to the first quintile, $\alpha \in [0.21, 0.4]$ to the second, and so forth. For each worker, we track their job changes, defined as any change in α . We also track which α quintile the worker transitioned from. We find that women have fewer overall job changes than men (94 percent). Notably, women were 63 percent less likely to have held a past job in the first quintile, indicating that those jobs are predominantly held by men.

Tables 2 and 3 partition the sample into those with a college degree and those without, as education shows different trends in job choice and promotions. As one would expect, the college subsample holds higher AFQT scores, wages, α , and rates of full-time work. Within the college subsample, men have on average slightly higher AFQT scores, by a tenth of a sample standard deviation, reflecting that college tends to be more selective for men than women, as 8.6 percent fewer men (3.5 percentage points) achieve a college degree. Men and women enter the labor market at similar ages and into jobs of similar complexity. Despite these similarities, women start with 11 percent lower wages on average. The gains in full-time employment associated with workers with a college degree accrue more to men than to women, as these women are 65 percent more likely than these men to work part-time, as opposed to 53 percent for the full sample. On average, women's monthly earnings are 66 percent of men's, 2 percent-

Table 3**Sample Means and Differences, No College Degree**

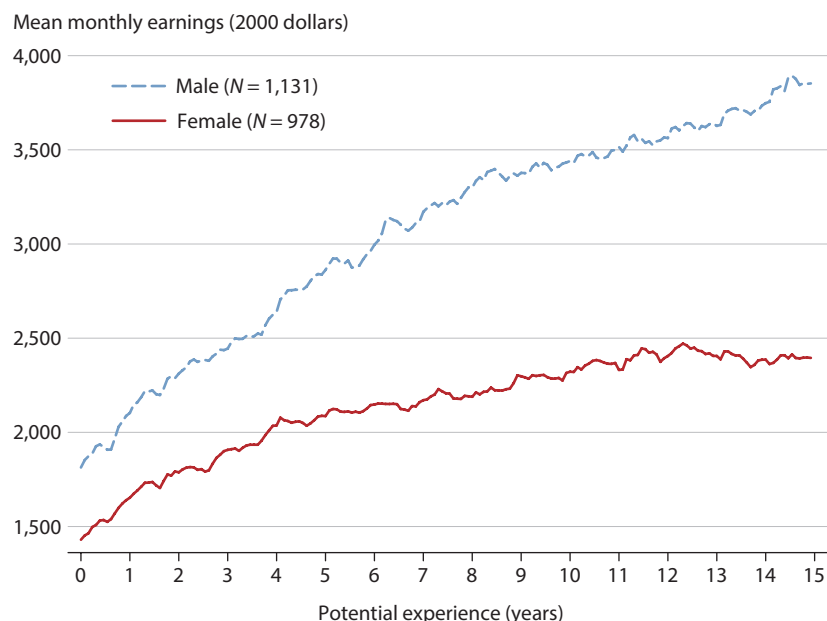
	Variable	Men	Women	% Δ	<i>p</i> -value
Pre-labor market	AFQT score (raw)	50	50	0	0.927
	AFQT score (normal)	0.4	0.4	-2	0.927
First job	Age	19.3	19.4	1	0.808
	Wage (\$/hr)	9	8	-13	0.000***
	Earnings (\$/mo)	1,498	1,098	-27	0.000***
	Full time (%)	76	63	-17	0.000***
	α ($\times 100$)	40	66	65	0.000***
Current job	Age	27	27	0	0.647
	Wage (\$/hr)	14	11	-20	0.000***
	Earnings (\$/mo)	2,392	1,620	-32	0.000***
	Labor (hrs/wk)	41	32.7	-20	0.000***
	Labor (hrs/mo)	173	146	-15	0.000***
	α ($\times 100$)	43	48	12	0.000***
Experience	Part time (wks)	28	69	144	0.000***
	Full time (wks)	319	266	-17	0.000***
	Job spells	13.8	12.7	-8	0.001***
	<i>N</i>	743	592	-151	-20

age points less than the full sample. Women hourly wages are 20 percent lower than men's. On average, women work 16 percent fewer hours than men. Both men and women with a college degree accrue more full-time experience and less part-time experience than their counterparts without a college degree. Unlike in the full sample, in the college subsample, women have more job changes, although these changes are not statistically significant. As with the full sample, women hold fewer jobs in the first α quintile, more in the second, and about the same in the third and above.

Section 3 explores these statistics and their trends in more detail and discusses different hypotheses to explain them.

3 GENDER GAPS OVER THE LIFE CYCLE

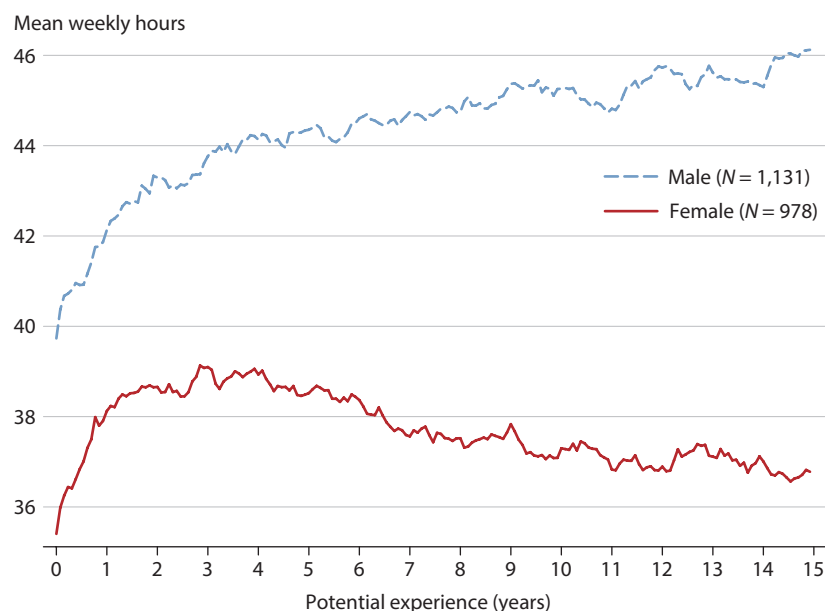
Figure 1 shows the evolution of the average monthly earnings for men and women for the first 15 years after individuals enter the labor market. The gender gap is positive when men and women enter the labor market and increases with their labor market experience. Figure 1 shows that when we consider all workers, the gender gap increases almost 30 percent during the first 5 years of labor market experience, 22 percent in the following 5 years (from

Figure 1**Mean Earnings by Gender and Career Age (All)**

year 5 to year 10). The fact that the gender pay gaps increases over the life cycle is a well-documented fact and can be partly attributed to an increasing difference in hours worked, labor market experience, the nature of jobs that men and women take, and promotion patterns. Note that while these factors can be attributed to differences in skills accumulated in the labor market in terms of human capital that workers accumulate with experience, those differences in human capital can be attributed to discrimination as well as preferences. It has been argued that women do more housework and take care of children more often than men and as a result work less and accumulate less human capital and work in jobs that provide more flexibility or demand fewer hours. However, this explanation does not rule out discrimination in the labor market, because the choices of how much time to spend on housework and child care may be partly driven by lower wages and lack of opportunity for promotions and jobs that require long hours but have high pay. While it is beyond the scope of this article to disentangle the fundamental factors driving the gaps, we proceed by documenting them and discuss explanations from the literature.

3.1 Gender Gaps in Task Complexity and Hours Worked

Two main factors that affect compensation are hours worked and the type of occupations and tasks men and women perform. Figures 2 to 4 document mean weekly hours worked by gender, career age, and education. Clearly, after the second year, the gap in hours worked grows substantially: 10 years after entry into the labor market, women with a college degree work

Figure 2**Mean Weekly Hours by Gender and Career Age (All)**

on average about 9 hours less than men; the gap increases slightly to 10.5 hours by year 15. The same pattern is observed for workers without a college degree, although the gap is smaller (7 hours by year 10 and 9 hours by year 15). Typically, monthly pay depends on hours worked and, in addition, many high-paying jobs which pay high wages (even when computing the per hour wage rates) are not flexible and require working full time and many times long hours. It is unclear whether women choose to work fewer hours, especially during childbearing years, and whether the increases in the hours-worked gaps are due to women spending more time caring for children or to discrimination and lack of opportunities. Specializing in home production and choosing jobs with fewer hours may be related to discrimination: If women have lower potential earning than men with similar skills, education, and qualifications, it might lead to women spending more time at home and men spending more time in the workplace.

To further explore the evolution of the gaps, we document the evolution of gaps in occupational task assignments. As shown in Antonovics and Golan (2012), occupations with higher demand for complex tasks are associated with higher pay and for black and white men are an important source of the increase in the racial pay gap between them over the life cycle (see Golan et al., 2019, and Golan and Sanders, 2019). Figure 5 shows that while job complexity may explain this pay gap for men, women are on average assigned to jobs with higher task complexity. This is perhaps less surprising, as in our sample women are on average more educated than men.

Figure 3

Mean Weekly Hours by Gender and Career Age (College)

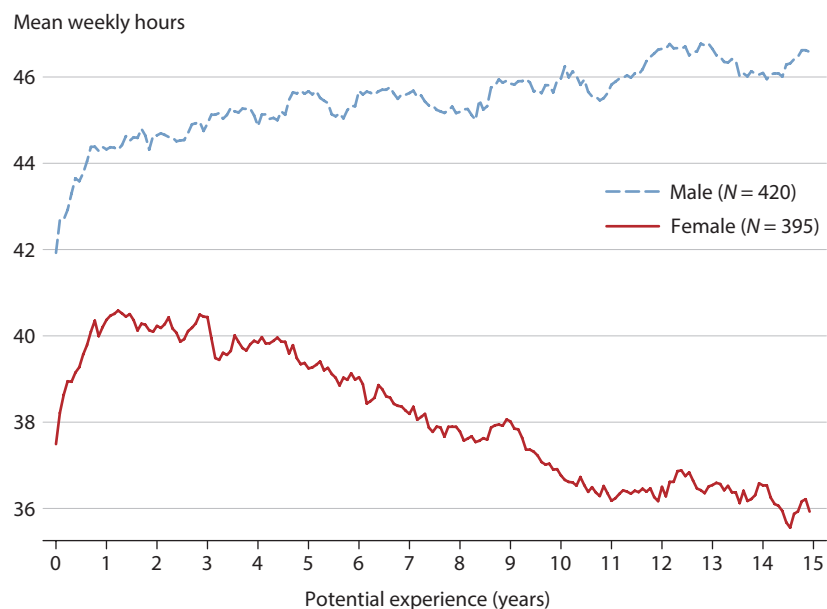


Figure 4

Mean Weekly Hours by Gender and Career Age (No College)

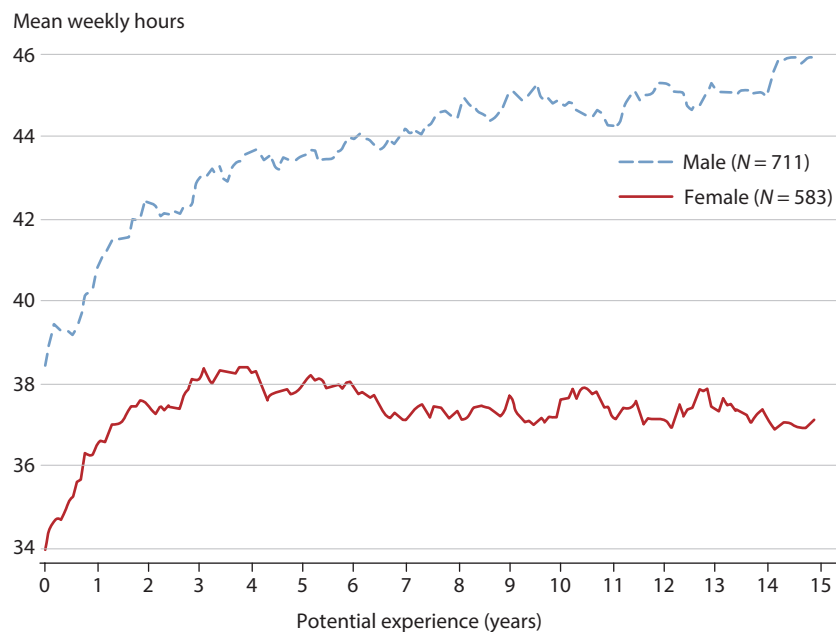
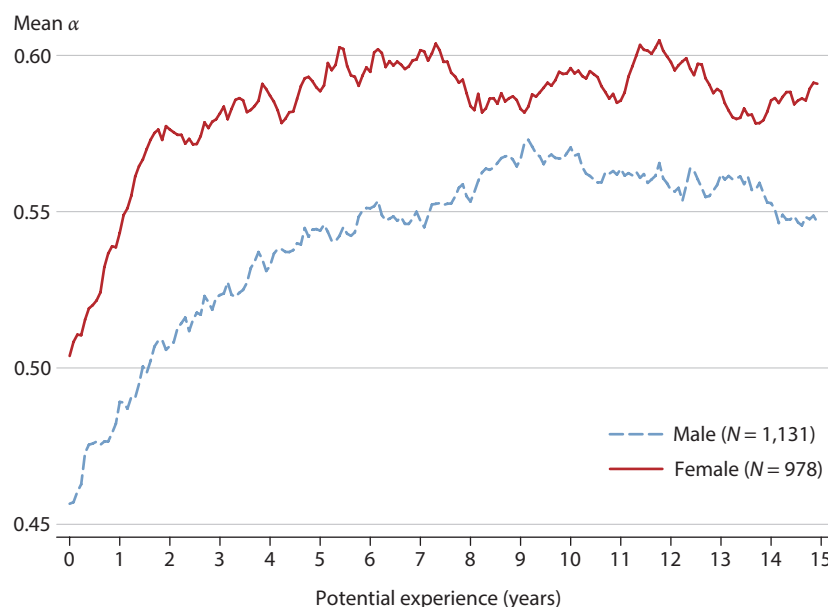


Figure 5**Mean Job Complexity by Gender and Career Age (All)**

Figures 6 to 7 reveal differences in patterns by education group. Among workers without a college degree, women are assigned to jobs with higher task complexity and the gap remains as workers age, although it is larger up to year 8 than it is afterward. Therefore, this factor does not seem to play an important role in the increase in gender earnings gap patterns of workers without a college degree. College-educated women, however, are assigned to jobs with lower demand for complex tasks about 3 years after they enter the labor market and the gap is mostly larger in later years. While the average growth patterns are similar for men and women without a college degree, they differ for the those with a college degree: College-educated women are not on average employed in jobs with exceedingly increasing job complexity after the first year, while college-educated men are— α increases on average for men for the first 10 years. These patterns may reflect differences in promotions and occupational changes for college-educated men and women.

Figure 6

Mean Job Complexity by Gender and Career Age (College)

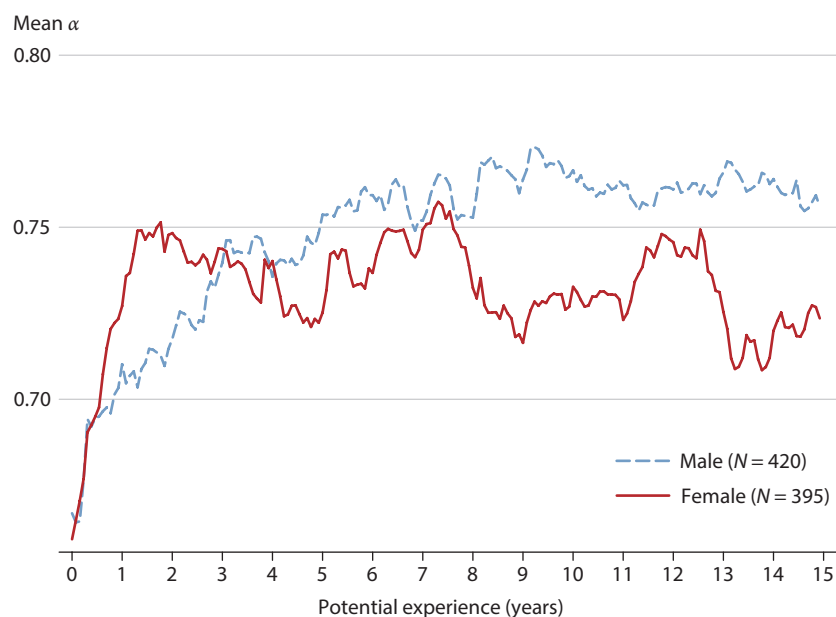
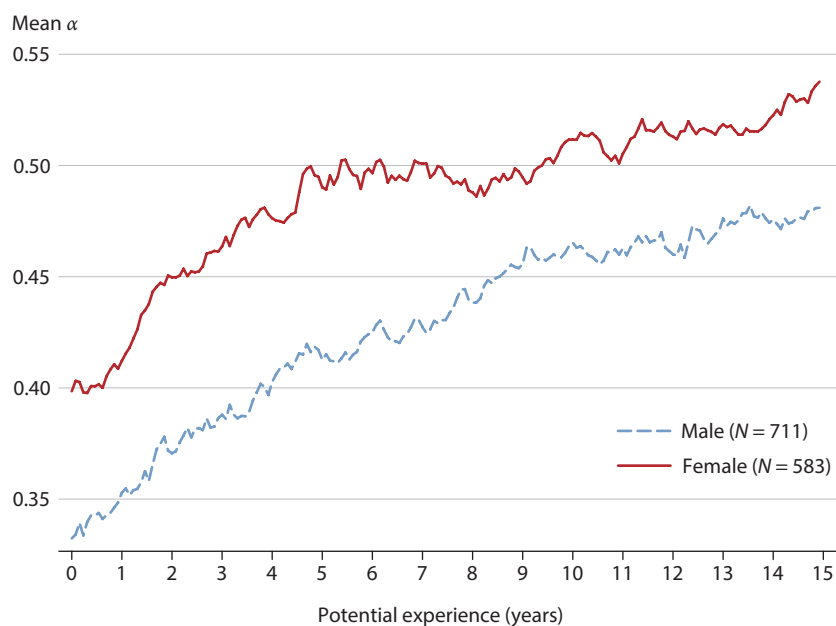


Figure 7

Mean Job Complexity by Gender and Career Age (No College)



3.2 Labor Market Experience

Working longer hours is associated with higher pay; however, workers accumulate experience and human capital over time, which is reflected in the pay and productivity of workers currently working a similar number of hours but having different levels of experience. To explore this potential explanation, we look at those who work full time consistently,¹¹ as they earn more on average and more men than women work full time consistently.¹² We construct a subsample of workers who work full time consistently (labeled FTC) throughout the survey; precisely, we require they work full time in at least 80 percent of the sampled weeks. Figures 8 and 9 present the female-to-male mean monthly earnings ratio for the entire sample and for the FTC subsample by education group. The figures show that, for both workers with and workers without a college degree who work full time most of their careers, the gap increases by less than it does for the sample overall. This finding suggests that education and labor market experience (measured by hours of work each month) play an important role in explaining the gender pay gap.

There are several possible explanations for this pattern. The first is that the composition of the sample changes. For example, if skilled women (skill can be formal education and training but also innate ability, which is unobserved by the researchers) are more likely to work full time consistently, then the wage gap at a later age reflects the fact that we are comparing the wages of less-skilled women to those of men when they are both young, while we are comparing the wages of more-skilled women to those of men when they are both older. (The group of men working full-time continuously can be more stable because both more-skilled and less-skilled men are likely to work full time.) The second explanation is that, while men still work more hours than women, the gap in hours declines in this group; so, the increase in experience (and, therefore, labor market skills) of women who work full time continuously is larger than that of men. The third explanation is that the wage gap reflects discrimination: Discrimination of women who consistently work full time declines over time. We elaborate about the third explanation next.

Gayle and Golan (2011) develop a model in which men and women choose whether to work and hours and occupations. The authors show that statistical discrimination causes a large gender gap in human capital in the form of accrued experience, which is affected by both participation in the labor market and working long hours. Statistical discrimination arises from asymmetric information and employers' costs of hiring workers. These hiring costs might be higher in some occupations than others, due to higher training costs, for example. Workers know their own future labor supply, but employers do not. Hence, employers form a priori beliefs on a worker's labor market attachment and hours worked based on statistical averages. Women are statistically more likely to reduce hours or take maternity leave; when they do, employers must pay a replacement hiring cost. Therefore, it is more costly, on average, for employers to hire women than men. For that reason, in a competitive equilibrium, employers pass this cost on to women through lower wages or by not hiring them at all. In their data, Gayle and Golan (2011) find the gender gap closes by age 35 for men and women who work full time continuously. This fact is consistent with the hypothesis that the gender gap could be driven by statistical discrimination, that is, the average lower labor supply of women caused

Figure 8

Gender Earnings Gap by Career Age (College)

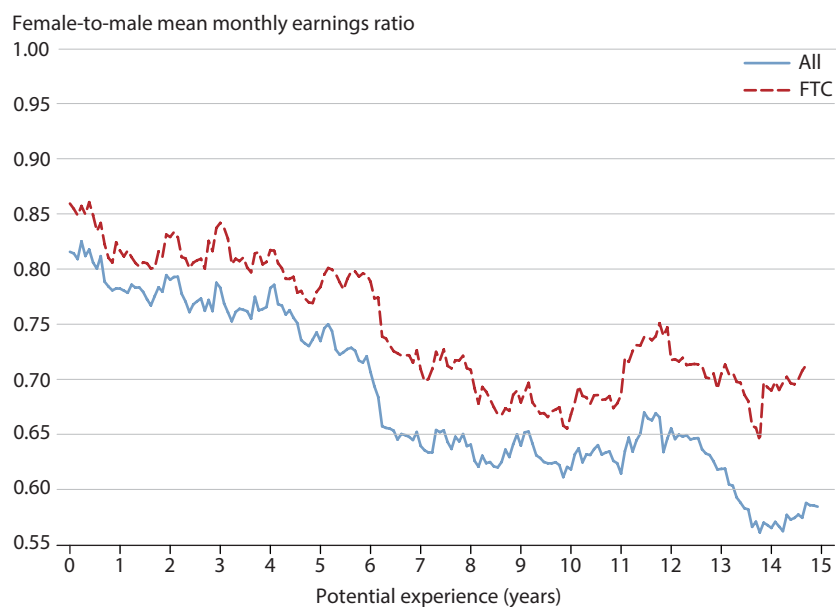
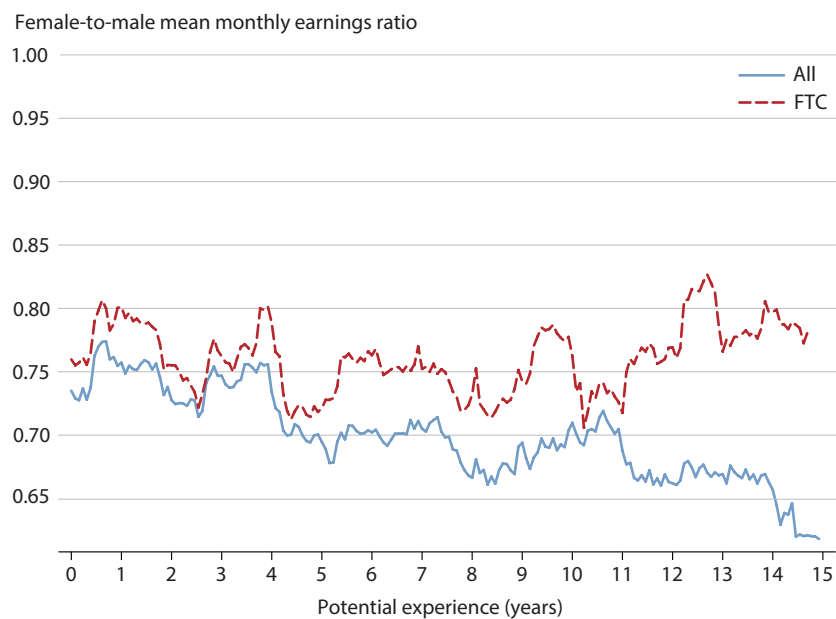


Figure 9

Gender Earnings Gap by Career Age (No College)



by family priorities that conflict with their careers. As a result, they receive lower wage offers, especially in occupations with large costs of hiring and high hours. However, women who consistently work high hours “signal” to employers that they are attached to the labor market. As a result, employers update their priors, reducing the pay gap for these women over time.¹³

4 OBSERVABLE DIFFERENCES AND THE GENDER EARNINGS GAPS

The patterns described above do not account for differences in composition between men and women, observable or not. To account for observable differences, we first regress earnings on observables, such as AFQT scores, and examine the correlation between the earnings gaps and experience gained over the life cycle.

Table 4 presents the results for the earnings regressions for the full sample, for the subsample of workers with a college degree, and for the subsample of workers without a college degree. Column 1 shows that after controlling for the skills workers bring into the labor market there is still a gender gap in earnings. Column 3 of Table 4 adds years of part-time and full-time labor market experience. Past history on hours worked reduces the gender earnings gap by 5 percent more for workers without a college degree, but it helps reduce the gap by 15 percent for workers with a college degree.

Controlling for current job complexity, Column 4 of Table 4 raises the gender gap 5 percent for workers with a college degree and by 15 percent for workers without a college degree, suggesting that men and women might sort differently into the two education groups. Column 5 adds controls for the worker’s initial job, both for job complexity and earnings. The results are very heterogeneous between the education groups. For both groups the gender gap decreases; but while initial job complexity has a positive effect on current earnings for workers without a college degree, it has a negligible effect for workers with a college degree. While controlling for observable characteristics that are endogenous, such as hours, experience, occupation, entry pay, and occupation, *does not* imply that there is no discrimination, we use the Blinder-Oaxaca decomposition to quantify below the importance of each of the observable differences.

4.1 Quantifying the Role of Observed Differences

We now present a succinct illustration of the Blinder-Oaxaca decomposition.¹⁴ For period t and worker i , estimate separate male (m) and female (f) ordinary least-squares (OLS) wage regressions (the i and t subscripts are hidden for clarity):

$$(1) \quad Y_m = X_m B_m + u_m$$

$$(2) \quad Y_f = X_f B_f + u_f,$$

where Y is wages, X is a vector of explanatory variables, B is a vector of coefficients, and u is an error term.

Let b_m and b_f be the OLS estimates of B_m and B_f . We denote mean values with an overbar. Then, since OLS with a constant term produces residuals with a zero mean, we have

Table 4**Gender Pay Gap Regressions, Full Sample and by Schooling**

	\$ Per month				
	(1)	(2)	(3)	(4)	(5)
A. Full sample					
Male	967 (54)	563 (48)	512 (48)	576 (47)	507 (51)
AFQT score (demeaned)	308 (29)	294 (27)	287 (26)	211 (25)	167 (23)
College degree	1,131 (68)	1,053 (62)	1,085 (62)	842 (63)	632 (82)
Labor (hrs/mo)		15.3 (0.7)	13.2 (0.7)	12.6 (0.7)	12.1 (0.6)
Experience, part time (yrs)			28 (12)	25 (12)	47 (12)
Experience, full time (yrs)			127 (5)	117 (5)	120 (5)
α				1,147 (87)	944 (85)
Entry pay (\$/mo)					0.24 (0.10)
Entry α					418 (140)
<i>N</i>	342,306	342,306	340,138	340,138	329,734
<i>R</i> ²	0.178	0.267	0.322	0.337	0.372
B. College					
Male	1,270 (118)	748 (102)	642 (103)	675 (100)	516 (92)
AFQT score (demeaned)	636 (81)	614 (73)	602 (73)	495 (69)	315 (69)
Labor (hrs/mo)		18.6 (1.3)	16.6 (1.4)	15.8 (1.4)	14.6 (1.3)
Experience, part time (yrs)			38 (26)	55 (26)	88 (23)
Experience, full time (yrs)			190 (11)	181 (11)	189 (11)
α				1,614 (211)	1,275 (223)
Entry pay (\$/mo)					0.51 (0.08)
Entry α					-36 (241)
<i>N</i>	128,546	128,546	128,228	128,228	123,276
<i>R</i> ²	0.095	0.180	0.257	0.273	0.329
C. No college					
Male	751 (46)	416 (42)	395 (43)	464 (42)	445 (42)
AFQT score	190 (26)	180 (24)	175 (24)	117 (23)	107 (22)
Labor (hrs/mo)		13.2 (0.7)	11.4 (0.7)	10.9 (0.7)	10.7 (0.6)
Experience, part time (yrs)			35 (13)	26 (12)	35 (12)
Experience, full time (yrs)			91 (4)	83 (4)	83 (4)
α				895 (75)	824 (69)
Entry pay (\$/mo)					0.12 (0.04)
Entry α					325 (99)
<i>N</i>	213,760	213,760	211,910	211,910	206,458
<i>R</i> ²	0.078	0.213	0.271	0.291	0.321

NOTE: Standard errors are in parentheses.

$$(3) \quad \bar{Y}_m - Y_f = b_m \bar{X}_m - b_f \bar{X}_f = b_m (\bar{X}_m - \bar{X}_f) + \bar{X}_f (b_m - b_f),$$

where $b_m(\bar{X}_m - \bar{X}_f)$ is the impact of gender differences in the explanatory variables; $(\bar{X}_m - \bar{X}_f)$ is evaluated using the male coefficients; and $b_m \cdot \bar{X}_f(b_m - b_f)$ is the unexplained differential and corresponds to the average female residual from the male wage equation, which corresponds to an experiment where we take a woman, give her characteristics, and reward her according to the male “reward” system. We report the first component below.

Table 5 shows the results for each of the three samples (full, college, and no college) for different models. For each model, the top part of each panel presents the differentials of the predicted values of monthly earnings between the two groups (men and women) as well as the fraction of the differential that can be explained with the included regressors and which fraction remains unexplained. The bottom part of each panel decomposes the explained component by regressor. For each panel, the sum of all regressors equals the “Total explained” line.

Panel A, for the human capital basic model, shows that AFQT scores, a college degree, hours, and part-time and full-time experience explain 51 percent of the observed earnings gap for the full sample. Hours worked explains 41 percent of the gender gap, or 80 percent of the explained gap. A college degree has a negative contribution, reflecting that a higher fraction of women than men have a college degree. For the subsample with a college degree, the variables of the human capital basic model explain 59 percent of the observed earnings gap, 8 percent more than for the full sample, with AFQT being the main driver of that increase. For workers without a college degree, the results are closer to those for the full sample.

Panel B, for the current job conditions extended model, adds α of the current job. For all three samples, this model explains less than the model in Panel A. The contribution of α is negative for the full sample and the noncollege-educated subsample, reflecting that women without a college degree work more-complex jobs. Among college-educated workers, job complexity does not explain a significant fraction of the gender earnings gap.

Finally, Panel C, for the entry job conditions extended model, adds α and earnings of the first job.¹⁵ By doing that, we account for additional unobserved heterogeneity of workers, that is, to the extent that pay reflects differences in initial skills and preferences. The results are very heterogeneous across samples. For the full sample, characteristics of a worker’s first job have a very significant effect in explaining the gender earnings gap, particularly so for initial earnings, which explains 10 percent of the total 52 percent explained. The negative contribution of current α falls, while entry α drives a part of the negative contribution. For the subsample of college-educated workers, first-job earnings explain 22 percent of the gender gap, increasing the fraction explained by all regressors to 67 percent. Allowing the model to account for first-job characteristics also allows part-time experience to have a negative contribution, reflecting the fact that more women in this group work fewer hours. As in Panel A, in Panel C, the decompositions for workers without a college degree are very similar to those for the full sample.

The results in this section suggest that human capital gained from work experience explains a large share of the gender pay gap at all education levels.

Table 5**Decomposing the Gender Pay Gap, Full Sample and by Schooling**

	Effect of gender gap in explanatory variables					
	Full sample		College degree		No college degree	
	\$ Per month	% Explained	\$ Per month	% Explained	\$ Per month	% Explained
A. Human capital basic model						
Mean male pay	3,044		4,166		2,412	
Mean female pay	2,118	70	2,805	67	1,663	69
Total pay gap	926	30	1,361	33	748	31
Total unexplained	451		556		350	
Total explained	475	51	805	59	398	53
College degree	-39	-4				
AFQT score	0	—	95	7	-4	-1
Experience, part time	-2	0	-7	—	-10	-1
Experience, full time	136	15	203	15	98	13
Labor (hrs/mo)	380	41	514	38	314	42
B. Current job conditions extended model						
Mean male pay	3,044		4,166		2,412	
Mean female pay	2,118	70	2,805	67	1,663	69
Total pay gap	926	30	1,361	33	748	
Total unexplained	500		584		401	
Total explained	426	46	777	57	347	46
College degree	31	-3				
AFQT score	0	—	80	6	-3	—
Experience, part time	2	—	-19	-1	-3	—
Experience, full time	128	13	194	14	91	12
Labor (hrs/mo)	369	40	495	36	307	41
α	-42	-5	26	2	-46	-6
C. Entry job conditions extended model						
Mean male pay	3,027		4,153		2,401	
Mean female pay	2,120	70	2,815	68	1,668	70
Total pay gap	906	30	1,338	32	733	30
Total unexplained	432		439		377	
Total explained	474	52	900	67	356	49
College degree	-26	-3				
AFQT score	1	—	48	4	-2	—
Experience, part time	-18	-2	-52	-4	-11	-2
Experience, full time	129	14	204	15	90	12
Labor (hrs/mo)	345	38	453	34	289	39
α	-37	-4	20	2	-45	-6
Entry α	-14	-2	-1	—	-12	-2
Entry pay (mo)	93	10	288	22	48	7

Table 6**Job and Wage Changes by Gender and Mover Category (All)**

	Weeks							
Men	1-50	51-100	101-150	151-200	201-250	251-300	301-350	All
Move up								
$E[\Delta\alpha]$	0.25	0.25	0.25	0.23	0.24	0.22	0.23	0.24
$E[\Delta W]$	2.03	0.81	1.42	1.58	1.56	1.30	0.76	1.36
$E[\Delta H]$	1.32	2.24	2.24	0.56	1.18	-0.42	0.55	1.19
N	463	495	449	414	373	352	341	2,887
Stayers								
$E[\Delta W]$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$E[\Delta H]$	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
N	54,730	56,419	56,490	56,569	56,365	56,065	55,782	392,420
Move down								
$E[\Delta\alpha]$	-0.24	-0.23	-0.23	-0.24	-0.23	-0.23	-0.22	-0.23
$E[\Delta W]$	1.51	0.63	0.70	1.01	1.02	1.19	1.30	1.03
$E[\Delta H]$	1.13	-0.04	-0.57	0.23	-0.55	-0.60	-0.85	-0.14
N	392	446	413	358	318	324	306	2,557

	Weeks							
Women	1-50	51-100	101-150	151-200	201-250	251-300	301-350	All
Move up								
$E[\Delta\alpha]$	0.24	0.23	0.24	0.22	0.23	0.22	0.23	0.23
$E[\Delta W]$	1.52	0.91	1.14	1.00	0.87	0.94	1.18	1.09
$E[\Delta H]$	3.04	1.40	1.38	1.01	-0.12	1.09	-0.06	1.20
N	369	388	345	322	290	274	276	2,264
Stayers								
$E[\Delta W]$	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
$E[\Delta H]$	0.01	0.00	0.00	0.00	0.00	0.00	-0.01	0.00
N	46,964	48,296	48,060	47,871	47,889	48,022	47,224	334,326
Move down								
$E[\Delta\alpha]$	-0.21	-0.21	-0.22	-0.23	-0.23	-0.22	-0.21	-0.22
$E[\Delta W]$	0.27	1.10	1.09	0.28	1.03	0.45	1.61	0.82
$E[\Delta H]$	1.06	-0.65	-1.03	-0.60	-0.78	-1.58	-1.63	-0.70
N	297	314	331	283	295	271	222	2,013

NOTE: For men, the weekly probability of a move is 1.39 percent: 0.74 percent up and 0.65 percent down. For woman, the weekly probability of a move is 1.28 percent: 0.68 percent up and 0.60 percent down. A change is any $|\Delta\alpha| \geq 0.01$ persisting more than six weeks. Gaps in work are ignored.

Table 7

Job and Wage Changes by Gender and Mover Category (College)

	Weeks							
	1-50	51-100	101-150	151-200	201-250	251-300	301-350	All
Men								
Move up								
$E[\Delta\alpha]$	0.27	0.26	0.28	0.21	0.24	0.21	0.21	0.24
$E[\Delta W]$	3.44	1.48	2.48	3.05	1.99	3.37	2.24	2.59
$E[\Delta H]$	2.48	2.46	1.73	1.12	1.69	-0.49	0.57	1.49
N	163	147	126	132	115	106	96	885
Stayers								
$E[\Delta W]$	0.00	0.00	0.00	0.01	0.01	0.00	-0.01	0.00
$E[\Delta H]$	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
N	20,571	21,180	21,240	21,272	20,864	20,653	20,402	146,182
Move down								
$E[\Delta\alpha]$	-0.24	-0.23	-0.23	-0.23	-0.21	-0.23	-0.23	-0.23
$E[\Delta W]$	1.51	0.86	-0.11	1.92	0.66	1.69	3.44	1.31
$E[\Delta H]$	2.65	-0.62	-0.48	-0.79	0.63	-1.48	-1.84	-0.24
N	112	159	124	109	92	95	86	777
	Weeks							
	1-50	51-100	101-150	151-200	201-250	251-300	301-350	All
Women								
Move up								
$E[\Delta\alpha]$	0.28	0.23	0.24	0.22	0.19	0.23	0.23	0.23
$E[\Delta W]$	2.21	1.50	1.36	1.95	1.53	2.04	1.61	1.77
$E[\Delta H]$	2.74	1.18	2.52	-0.08	-0.40	0.37	-1.47	0.88
N	156	128	108	110	96	101	94	793
Stayers								
$E[\Delta W]$	0.00	0.00	0.01	0.01	0.01	-0.01	0.00	0.00
$E[\Delta H]$	0.01	-0.01	0.00	0.00	0.00	0.00	-0.01	0.00
N	19,067	19,820	19,612	19,363	19,364	19,483	18,875	135,584
Move down								
$E[\Delta\alpha]$	-0.21	-0.24	-0.25	-0.24	-0.23	-0.19	-0.22	-0.23
$E[\Delta W]$	-0.32	1.01	2.10	-0.82	1.35	0.68	3.30	0.96
$E[\Delta H]$	0.83	-1.75	-2.78	0.37	-1.52	-1.77	-0.74	-1.05
N	102	110	110	111	109	84	77	703

NOTE: For men, the weekly probability of a move is 1.14 percent: 0.61 percent up and 0.53 percent down. For woman, the weekly probability of a move is 1.06 percent: 0.55 percent up and 0.52 percent down. A change is any $|\Delta\alpha| \geq 0.01$ persisting more than six weeks. Gaps in work are ignored.

Table 8

Job and Wage Changes by Gender and Mover Category (No College)

	Weeks							
Men	1-50	51-100	101-150	151-200	201-250	251-300	301-350	All
Move up								
$E[\Delta\alpha]$	0.25	0.25	0.23	0.23	0.24	0.22	0.24	0.24
$E[\Delta W]$	1.26	0.52	1.01	0.89	1.38	0.40	0.18	0.82
$E[\Delta H]$	0.67	2.14	2.44	0.30	0.95	-0.39	0.55	1.05
N	300	348	323	282	258	246	245	2,002
Stayers								
$E[\Delta W]$	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$E[\Delta H]$	0.02	0.00	0.01	0.00	0.01	0.01	0.00	0.01
N	34,159	35,239	35,250	35,297	35,501	35,412	35,380	246,238
Move down								
$E[\Delta\alpha]$	-0.23	-0.23	-0.23	-0.24	-0.24	-0.23	-0.22	-0.23
$E[\Delta W]$	1.51	0.50	1.05	0.61	1.17	0.98	0.47	0.91
$E[\Delta H]$	0.51	0.28	-0.60	0.67	-1.06	-0.22	-0.43	-0.09
N	280	287	289	249	226	229	220	1,780

	Weeks							
Women	1-50	51-100	101-150	151-200	201-250	251-300	301-350	All
Move up								
$E[\Delta\alpha]$	0.21	0.23	0.24	0.23	0.25	0.22	0.23	0.23
$E[\Delta W]$	1.01	0.62	1.04	0.50	0.55	0.30	0.95	0.72
$E[\Delta H]$	3.25	1.51	0.88	1.58	0.01	1.51	0.68	1.37
N	213	260	237	212	194	173	182	1,471
Stayers								
$E[\Delta W]$	0.00	-0.01	0.00	0.00	-0.01	0.01	0.00	0.00
$E[\Delta H]$	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00
N	27,897	28,476	28,448	28,508	28,525	28,539	28,349	198,742
Move down								
$E[\Delta\alpha]$	-0.21	-0.20	-0.20	-0.23	-0.23	-0.24	-0.21	-0.21
$E[\Delta W]$	0.58	1.15	0.60	0.99	0.84	0.35	0.71	0.74
$E[\Delta H]$	1.19	-0.04	-0.16	-1.23	-0.35	-1.49	-2.12	-0.52
N	195	204	221	172	186	187	145	1,310

NOTE: For men, the weekly probability of a move is 1.54 percent: 0.81 percent up and 0.72 percent down. For woman, the weekly probability of a move is 1.40 percent: 0.74 percent up and 0.66 percent down. A change is any $|\Delta\alpha| \geq 0.01$ persisting more than six weeks. Gaps in work are ignored.

Some potential causes for the gender pay gap could be first that workers accumulate skills and learn while working. Because men work on average more hours, they accumulate more skills. It could also be that workers are endowed with skills but workers are uncertain about the skills they have. Workers learn about their skills over time; that is, jobs are experienced goods (as suggested by Antonovics and Golan, 2012) that help workers learn about themselves and sort into jobs for which they are better matched. We explore next the role of learning through job turnover.

5 JOB CHOICE AND TURNOVER

As shown above, hours worked and past hours are important factors determining the gender pay gap, while occupational changes might be an important factor in understanding the gender pay gap for college-educated workers. On average, job transitions are associated with wage growth over the life cycle. Specifically, Antonovics and Golan (2012) find that for men who change occupations, on average, wages increase. This pattern holds for workers who move up in terms of job complexity as well as for workers who move down, although the mean increase in wages associated with turnover is smaller for the latter group. There are several explanations consistent with these patterns. An important factor is that workers are sorted into matches that better fit their skills over time, which can be for several reasons. One is learning by doing (e.g., Jovanovic and Nyarko, 1970), through which workers learn how to perform tasks and accordingly move up the job ladder, causing wages to increase over time. A second is search frictions: Workers may not always find the jobs that best suit their qualifications initially, but over time they search and move when they find better matches. Another explanation is that workers do not always know which type of job matches their skills best and then learn this through experience (Jovanovic, 1979; Miller, 1984; and Antonovics and Golan, 2012, among others). In this article, we separately document the patterns of occupational changes and wage changes for men and women. Tables 6 to 8 document the patterns by weeks of employment. There are job changes during the 350 weeks but more occur in the first 150 weeks. Workers who move up have larger wage gains than those who move down, but on average the hourly wage changes are positive. Men, on average, have about 25 percent larger hourly wage gains when changing occupations. For them, moving up is associated with an additional 1.2 hours a week and moving down is associated with a reduction in hours, but the average changes are small. We find similar patterns for women, who on average move less often and for smaller raises.

Wage changes are much smaller (less than \$1 per hour) among workers without a college degree. While women without a college degree have a smaller wage increase when they move than women with a college degree, the increase in their gender pay gap is less than that for women with a college degree, as both a fraction and an amount. For workers without a college degree who move up, on average, men work 1.1 more hours per week and women 1.4 hours per week; the gender gap in hours from a promotion is the reverse of that for the college group. Of workers who move down, on average, men work about the same hours and women 0.5 hours less.

Table 9**Average Marginal Effects on Turnover (College)**

	(1)	(2)	(3)	(4)	(5)	(6)
Male	0.0218 (1.71)	0.0238 (1.83)	0.0385** (2.92)	0.0381** (3.07)	0.0413** (3.27)	0.0359** (3.01)
Age	-0.0278*** (-25.51)	-0.0280*** (-25.31)	-0.0250*** (-22.56)	-0.0303*** (-21.62)	-0.0306*** (-21.89)	-0.0194*** (-8.78)
AFQT score		-0.0127 (-1.48)	0.0117 (1.41)	0.0136 (1.74)	0.0121 (1.55)	0.0138 (1.87)
Hours (yr)			-0.0632** (-2.94)	-0.0541** (-2.58)	-0.0546** (-2.60)	-0.0631** (-2.90)
α			-0.347*** (-13.92)	-0.324*** (-13.27)	-0.339*** (-12.82)	-0.341*** (-13.18)
Job changes				0.00945*** (5.84)		
Job changes (1)					-0.00752 (-0.70)	-0.00485 (-0.46)
Job changes (2)					0.00653 (0.92)	0.0125 (1.72)
Job changes (3)					0.00641 (1.29)	0.0134** (2.62)
Job changes (4)					0.0158*** (4.45)	0.0242*** (6.59)
Job changes (5)					0.0103*** (3.85)	0.0138*** (5.14)
Part-time experience						-0.0303*** (-5.25)
Full-time experience						-0.0180*** (-6.33)
N	11,488	11,206	11,206	11,206	11,206	1,155

NOTE: *t*-statistics are in parentheses. **p* < 0.05, ***p* < 0.01, ****p* < 0.001.

Table 9 shows a logit regression of the probability of a job change¹⁶ next year. Columns 1 and 2 show that men are more likely than women to change jobs, all else equal, for both education groups. To control for job characteristics, we add job complexity to the regression as well as hours, since hours and α may imply different types of jobs. Columns 3 to 6 show that job characteristics increase the gender gap in the probability of a job change. Column 3 shows that conditional on α and hours, college-educated men are 3.9 percentage points likelier than college-educated women to change jobs.¹⁷

Table 10 shows the pattern also holds for workers without a college degree. Column 3 shows conditional on job complexity and hours, noncollege-educated men are 4.8 percentage point more likely than noncollege-educated woman to change jobs. Tables 11 to 12 repeat the effect for promotions¹⁸ since promotions bring greater wage gains on average. Column 1 of

Table 10**Average Marginal Effects on Turnover (No College)**

	(1)	(2)	(3)	(4)	(5)	(6)
Male	0.0345*** (3.52)	0.0349*** (3.50)	0.0479*** (4.54)	0.0410*** (4.13)	0.0431*** (4.19)	0.0360*** (3.62)
Age	-0.0215*** (-25.29)	-0.0222*** (-25.94)	-0.0209*** (-23.87)	-0.0277*** (-23.57)	-0.0288*** (-23.38)	-0.0185*** (-9.62)
AFQT score		-0.00996 (-1.84)	-0.00438 (-0.80)	-0.00359 (-0.70)	-0.00480 (-0.93)	-0.00334 (-0.67)
Hours (yr)			-0.112*** (-7.02)	-0.104*** (-6.72)	-0.110*** (-7.07)	-0.117*** (-7.34)
α			-0.0672*** (-3.64)	-0.0604*** (-3.39)	-0.0701*** (-3.79)	-0.0649*** (-3.55)
Job changes				0.00863*** (8.70)		
Job changes (1)					0.0101*** (3.45)	0.0155*** (5.12)
Job changes (2)					0.0132*** (4.46)	0.0206*** (6.73)
Job changes (3)					0.0146*** (4.53)	0.0216*** (6.38)
Job changes (4)					0.0161*** (5.11)	0.0223*** (6.69)
Job changes (5)					0.00158 (0.60)	-0.00413 (-1.48)
Part-time experience						-0.0272*** (-6.19)
Full-time experience						-0.0151*** (-6.09)
<i>N</i>	19,880	19,106	19,106	19,106	19,106	18,883

NOTE: *t*-statistics are in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 13 shows that college-educated men have a 2 percentage point higher probability of a promotion, but Column 3 shows the gap is smaller and insignificant when we control for α and hours. Column 1 of Table 14 shows that noncollege-educated men have no significantly greater probability of a promotion than women, but Column 3 shows that conditional on α and hours, noncollege-educated men are 3 percentage points less likely than noncollege-educated women to be promoted. Thus, the higher turnover probability for men without a college degree is due to changes to a lower α , as seen in Column 3 of Table 14. As discussed above, these patterns are consistent with a theory of learning and sorting, where workers sort into better-matching jobs; thus, men may be more likely to change jobs and find a better match on average.

The question of why women are less likely to change jobs has several possible explanations. One explanation, consistent with learning and sorting theories, is that because women spend

Table 11**Average Marginal Effects on Promotion (College)**

	(1)	(2)	(3)	(4)	(5)	(6)
Male	0.0223** (2.61)	0.0212* (2.45)	0.00890 (0.88)	0.00890 (0.88)	0.0172 (1.75)	0.0127 (1.34)
Age	-0.0151*** (-18.90)	-0.0151*** (-18.68)	-0.00969*** (-12.08)	-0.00978*** (-7.69)	-0.0101*** (-8.07)	-0.00361* (-2.04)
AFQT score		0.00551 (0.93)	0.0415*** (5.96)	0.0415*** (5.97)	0.0316*** (4.93)	0.0327*** (5.26)
Hours (yr)			0.0189 (1.17)	0.0190 (1.17)	0.0260 (1.65)	0.0177 (1.10)
α			-0.557*** (-24.57)	-0.557*** (-23.74)	-0.622*** (-26.11)	-0.617*** (-26.00)
Job changes				0.000155 (0.10)		
Job changes (1)					-0.0400*** (-4.64)	-0.0377*** (-4.53)
Job changes (2)					-0.0195*** (-3.44)	-0.0157** (-2.67)
Job changes (3)					-0.00979* (-2.53)	-0.00589 (-1.47)
Job changes (4)					0.000850 (0.27)	0.00532 (1.64)
Job changes (5)					0.0135*** (6.36)	0.0147*** (6.76)
Part-time experience						-0.0197*** (-4.31)
Full-time experience						-0.00996*** (-4.50)
N	9,984	9,753	9,753	9,753	9,753	9,702

NOTE: *t*-statistics are in parentheses. **p* < 0.05, ***p* < 0.01, ****p* < 0.001.

less time working on average they acquire less information about their own skills and therefore are less likely to change jobs for a better match; this explanation may imply that women are less likely to be in jobs that are a good match for their skills. It is also possible, however, that women are less likely to change jobs for other reasons, such as a lower propensity to move to jobs that require a location change due to family considerations (see Gemici, 2011, and Flabbi and Mabli, 2018, among others). Another possibility is that women are less likely to receive offers due to discrimination (see Flabbi, 2010, for a search model with gender discrimination).

Table 12

Average Marginal Effects on Promotion (No College)

	(1)	(2)	(3)	(4)	(5)	(6)
Male	0.0131 (2.35)	0.0125 (2.19)	−0.0302** (−3.77)	−0.0336** (−4.27)	−0.0152 (−1.99)	−0.0166 (−2.14)
Age	−0.0108** (−19.33)	−0.0110** (−19.37)	−0.00629** (−10.24)	−0.00935** (−9.96)	−0.0101** (−10.35)	−0.00772** (−4.76)
AFQT score		0.000579 (0.19)	0.0339** (8.32)	0.0338** (8.45)	0.0267** (7.03)	0.0274** (7.18)
Hours (yr)			−0.000871 (−0.07)	0.00300 (0.25)	0.00155 (0.12)	−0.00159 (−0.12)
α			−0.581** (−36.89)	−0.578** (−37.32)	−0.658** (−42.25)	−0.657** (−41.85)
Job changes				0.00357** (4.68)		
Job changes (1)					−0.0159** (−6.45)	−0.0145** (−5.53)
Job changes (2)					0.00124 (0.54)	0.00321 (1.28)
Job changes (3)					0.0163** (6.75)	0.0177** (6.66)
Job changes (4)					0.0239** (9.76)	0.0253** (9.44)
Job changes (5)					0.00341 (1.61)	0.00200 (0.85)
Part-time experience						−0.00583 (−1.66)
Full-time experience						−0.00328 (−1.54)
<i>N</i>	19,649	18,878	18,878	18,878	18,878	18,660

NOTE: *t*-statistics are in parentheses. **p* < 0.05, ***p* < 0.01, ****p* < 0.001.

Table 13**Average Marginal Effects on Demotion (College)**

	(1)	(2)	(3)	(4)	(5)	(6)
Male	0.000846 (0.12)	0.000978 (0.14)	-0.00227 (-0.26)	-0.00226 (-0.26)	-0.0103 (-1.21)	-0.00627 (-0.76)
Age	0.0137** (19.62)	0.0137** (19.30)	0.00854** (12.08)	0.00872** (7.80)	0.00902** (8.20)	0.00376 (2.44)
AFQT score		0.00327 (0.68)	-0.0356** (-5.48)	-0.0356** (-5.50)	-0.0268** (-4.61)	-0.0277** (-4.90)
Hours (yr)			-0.0168 (-1.19)	-0.0171 (-1.20)	-0.0236 (-1.72)	-0.0141 (-1.02)
α			0.513** (24.28)	0.512** (23.57)	0.569** (26.23)	0.567** (26.24)
Job changes				-0.000284 (-0.21)		
Job changes (1)					0.0389** (4.83)	0.0368** (4.72)
Job changes (2)					0.0181** (3.51)	0.0148* (2.75)
Job changes (3)					0.00764 (2.24)	0.00446 (1.26)
Job changes (4)					-0.00169 (-0.61)	-0.00522 (-1.82)
Job changes (5)					-0.0116** (-6.34)	-0.0126** (-6.69)
Part-time experience						0.0173** (4.12)
Full-time experience						0.00787** (4.08)
N	11,429	11,150	11,150	11,150	11,150	11,099

NOTE: t-statistics are in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 14

Average Marginal Effects on Demotion (No College)

	(1)	(2)	(3)	(4)	(5)	(6)
Male	−0.00127 (−0.23)	−0.000327 (−0.06)	0.0326*** (4.15)	0.0360*** (4.66)	0.0168* (2.25)	0.0183* (2.42)
Age	0.00995*** (18.24)	0.0101*** (18.16)	0.00617*** (10.27)	0.00925*** (10.11)	0.00993*** (10.48)	0.00782*** (4.93)
AFQT score		0.00516 (−1.68)	−0.0331*** (−8.23)	−0.0331*** (−8.37)	−0.0264*** (−7.04)	−0.0270*** (−7.15)
Hours (yr)			−0.000117 (−0.01)	−0.00386 (−0.33)	−0.00236 (−0.19)	0.00137 (0.11)
α			0.491*** (29.61)	0.488*** (29.89)	0.565*** (34.71)	0.564*** (34.29)
Job changes				0.00361*** (−4.86)		
Job changes (1)					0.0165*** (6.46)	0.0154*** (5.71)
Job changes (2)					−0.00215 (−0.94)	−0.00388 (−1.58)
Job changes (3)					−0.0160*** (−7.00)	−0.0172*** (−6.83)
Job changes (4)					−0.0219*** (−9.42)	−0.0230*** (−9.06)
Job changes (5)					−0.00344 (−1.66)	−0.00222 (−0.97)
Part-time experience						0.00572 (1.67)
Full-time experience						0.00281 (1.36)
N	19,450	18,693	18,693	18,693	18,693	18,472

NOTE: *t*-statistics are in parentheses. **p* < 0.05, ***p* < 0.01, ****p* < 0.001.

6 CONCLUSION

This article documents life-cycle gender differences in the labor market outcomes using longitudinal data of a cohort of individuals, NLSY79. As in other datasets, the gender pay gap increases with age. We find that the gap in weekly hours worked between men and women increases substantially as workers become more experienced. Quantifying the magnitude of the observable variables in the datasets for college- and noncollege-educated workers demonstrates that hours worked is indeed the largest observable variable in the explained gender gap. More than half of the gap is explained by differences in current hours worked and full-time work experience. Adding occupations and pay at the entry-level explains an additional 8 per-

cent of the gender pay gap between workers with a college degree and decreases by 4 percent the explained gap between workers without a college degree.

These gaps, however, do not reveal the fundamental factors that drive these differences. Hours, experience, and occupations are choices that could be driven by differences in the preferences of men and women (such as time spent at home caring for children) as well as labor market discrimination (see Gayle and Golan, 2011, for a theory in which occupational choice, hours worked, and experience are affected by discrimination).

We then focus on patterns in occupational changes over the life cycle. It is well documented that a large part of wage growth occurs when workers change jobs. We find that college-educated men, on average, move into occupations with higher demand for complex tasks and skills, while college-educated women on average do not move into such occupations after the first 2 years in the labor market.¹⁹ We further show that women are less likely to change occupations and that this pattern remains after accounting for other observable differences. Moreover, on average, wages grow when workers change occupations, but on average the growth is smaller for women. We discuss several theories of sorting and turnover consistent with these patterns. Labor market gaps can be the result of differences in the preferences of men and women, a result of allocation of time within the household, as well as discrimination. While it is beyond the scope of this paper to separate these elements, these are important questions for us to address in future research. ■

NOTES

- ¹ See Blau and Kahn (2017) for a comprehensive review on the trends in the gender wage gap.
- ² As shown in Gayle and Golan (2011), estimating for women who work full time continuously, the gender earnings gap declines and ultimately disappears by the time women are in their mid-30s.
- ³ See Goldin (2014). A model that gives rise endogenously to high returns to working long hours is developed in Gayle and Golan (2011).
- ⁴ For example, see Bertrand, Goldin, and Katz (2010) for analysis of women with an MBA and Gayle, Golan, and Miller (2012) for analysis of the market for top executives, among others.
- ⁵ For example, O'Neill (2005) finds that after adding occupations to the wage regression that controls for experience, education and test scores have little effect on the remaining "unexplained" gender pay gap in 2000 for the NLSY79 cohort. Using the PSID data, Blau and Kahn (2017) find that occupation explains one-tenth of the gender wage gap in 1980 and one-third in 2010. There are age differences and differences in variable definitions and controls in the different studies. In this study, we document the evolution of occupational tasks over the life cycle and the role of these changes and occupational transition in the observed gaps.
- ⁶ This is consistent with the finding in Gayle and Golan (2011) that the gender hourly wage gap closes and Golan and Hincapié (2016).
- ⁷ College major choices tend to be different for men and women partly because certain majors that women choose are associated with greater job flexibility. See Bronson (2014).
- ⁸ AFQT scores are routinely used as a measure of cognitive ability.
- ⁹ We use the official Bureau of Labor Statistics definition of full-time employment. For robustness, we check other thresholds at five-hour intervals from 20 to 40 and find that the Bureau of Labor Statistics definition also happens to yield the greatest empirical tractability.
- ¹⁰ Compiled by the Committee on Occupational Classification and Analysis at the National Academy of Sciences.

- ¹¹ We define “consistent” here as 80 percent of weeks.
- ¹² This has been documented for the differences in the median and average wage gaps by Gayle and Golan (2011) and Golan et al. (2016) using PSID data. We document the difference in monthly earnings instead of wages here and explore how it differs by education groups.
- ¹³ Another explanation is that there is sample selection. That is, women who work full-time consistently are on average increasingly selected and have higher ability than men with the same pattern of labor supply. Gayle and Golan (2011) account for that factor as well in their structural analysis and find evidence for statistical discrimination.
- ¹⁴ See Blau and Kahn (2017). We deviate by using wages rather than log wages. We also copyedit this passage.
- ¹⁵ Since women’s α changes drastically in the first 1.5 years, we also tested defining the entry α as the α after 1 year, and as the maximum α over the first 2 years, but these tests did not change the results substantially.
- ¹⁶ A job change (or turnover) is as any absolute change in α by 0.01 or more.
- ¹⁷ Using data for top executives, Gayle, Limor, and Miller (2012) find that women executives are less likely than men to change firms.
- ¹⁸ A promotion is any $\Delta\alpha > 0.05$, that is, more than half a decile.
- ¹⁹ This is not the case for workers without a college degree.

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More Stories of Unconventional Monetary Policy

Christopher J. Neely and Evan Karson

This article extends the work of Fawley and Neely (2013) to describe how major central banks have evolved unconventional monetary policies to encourage real activity and maintain stable inflation rates from 2013 through 2019. By 2013, central banks were moving from lump-sum asset purchase programs to open-ended asset purchase programs, which are conditioned on economic conditions, careful communication strategies, bank lending programs with incentives, and negative interest rates. This article reviews how central banks tailored their unconventional monetary methods to their various challenges and the structures of their respective economies. (JEL E51, E58, E61, G12)

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1 INTRODUCTION

Central banks worldwide responded to the Financial Crisis of 2007-09 with a variety of measures: emergency lending, conventional interest rate reductions, and eventually unconventional monetary policy (UMP). There is no hard and fast distinction among emergency lending, conventional monetary policy, and UMP; but emergency lending is narrowly focused and temporary, while monetary policy broadly and persistently changes interest rates and the availability of credit. Similarly, conventional monetary policy works through positive short-term interest rates, while UMPs influence medium- and long-term rates or facilitate credit in specific markets or—most broadly—use monetary policy in unusual ways to influence prices and economic activity.

Initial lending and monetary policy actions aimed to stabilize the financial sector, but central banks soon turned to stimulating growth with UMPs, which can be grouped into communication (i.e., “forward guidance” [FG]), asset purchases, conditional bank lending programs, and negative interest rates. Asset purchases and FG affect long-term interest rates

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and other asset prices. Conditional bank lending programs create incentives for banks to lend to the nonfinancial sector. Negative interest rates on deposits broadly affect asset prices in a manner similar to that of conventional declines in short-term interest rates. Foreign exchange management—that is, pegs and sterilized and unsterilized intervention—are not uncommon, even for developed economies, but might be considered UMPs.

UMPs are usually implemented because short-term interest rates have reached the “zero lower bound” and central banks have little or no scope to lower them further.¹ In such a low interest rate environment, central banks can still use UMPs, such as FG and asset purchases, to reduce long yields, raise stock prices, increase employment, and promote price stability.

Short-term interest rates have rarely reached the zero lower bound in postwar history, but such events may be common in the future. Many observers believe the global economy faces a long-term, low interest rate environment in which conventional short-term interest rate tools may have limited scope to stimulate the economy (Summers, 2016). For example, the Bank of Canada’s policy report forecasts that the neutral Canadian policy rate is now only 1.75 to 2.75 percent (Bank of Canada, 2020). In contrast, the Bank of Canada’s overnight rate averaged 7 percent from 1960 through 2007.

Central banks can implement unconventional policies quickly and flexibly, rendering those policies important contingency tools of stabilization policy, alongside conventional interest rate policy. Given that economists and policymakers widely perceive fiscal policy to be unwieldy and slow in practice, central banks have become “the only game in town” as Mohamed El-Erian described the Fed (Fischer, 2016).

A great deal of research has examined the UMP effects on financial markets and the macroeconomy. The backbone of such research is a set of theoretical models that suggest how such policies might affect real activity and prices through asset prices. Several types of studies indicate that UMP announcements strongly influenced domestic and international asset prices, including sovereign and corporate bonds, exchange rates, and stock prices. These price effects changed lending and portfolio behavior of individuals and financial institutions. There is greater uncertainty about how UMP affects the real economy, but both calibrated dynamic stochastic general equilibrium models and structural vector autoregression studies imply that UMP significantly stimulated output and prices. Bhattarai and Neely (forthcoming) survey the literature on the theory of UMP and its effects on financial markets and the macroeconomy.

Researchers have paid much less attention to the motivations, methods, and institutional details of the internationally varied unconventional programs than they have to the impact of such policies. Fawley and Neely (2013) describe and compare the quantitative easing (QE) and related maturity extension programs of the Federal Reserve (Fed), the Bank of England (BOE), the European Central Bank (ECB), and the Bank of Japan (BOJ) from 2008-12. During this period, all four major central banks provided unconventional monetary accommodation, although their efforts differed in extent and design.

This article complements Fawley and Neely (2013) by describing the unconventional policies of major central banks both prior to the crisis and from 2013 through 2019, during which time the four major central banks faced different challenges. With a recovering economy, the Fed first reduced then removed additional unusual monetary accommodation before

moving to normalize monetary conditions in 2014-18. Having pursued a milder easing campaign in 2008-12, the BOJ substantially increased accommodation in 2013, aggressively purchasing assets, lending to banks, and imposing negative deposit rates before eventually explicitly targeting long yields. The ECB used more aggressive measures, including negative deposit rates, conditional bank lending programs, and asset purchases in 2014-16 to counter undesired disinflation. Having aggressively eased policy in 2009-12, the BOE maintained steady but accommodative policies from 2013-16 and did not resume easing in earnest until after the 2016 Brexit vote. The coverage of this article ends at the end of 2019 because central banks shifted policies radically again in 2020:Q1 to respond to economic conditions associated with the unprecedented COVID-19 crisis. Haas, Neely, and Emmons (2020) cover those central bank reactions.

To provide the reader with an understanding of the states of their respective economies and the stances of their monetary policies at the start of 2013, we briefly review the nonstandard policy measures of the Fed, the BOE, the ECB, and the BOJ from 2000 through 2012. The article will then review the policies of the major central banks from 2013 through 2019.

2 TYPES OF UNCONVENTIONAL MONETARY POLICIES

Conventional monetary policy acts on current and near-term-expected short-term interest rates to influence prices and economic activity through a variety of potential channels that mostly function through asset prices. Although the line between conventional and unconventional policy is often blurry, unconventional policies typically are defined as those that directly influence long yields and exchange rates, push short rates below zero, explicitly create incentives for lending, and/or confront financial frictions by purchasing particular types of assets.

To broadly influence long yields, central banks purchase quantities of long-term bonds and provide expansionary FG. The purchase of long-term bonds may reduce long yields through one or more of three channels: “duration risk,” “local supply,” or “signaling.”

Duration risk is the sensitivity of bond prices to changes in the level of the yield curve, and long-term bonds have more duration risk. By buying long-term bonds, central banks remove the amount of duration risk in the hands of the public, which might reduce the risk premium that market participants demand to hold long bonds and thus reduce the yields bonds must pay.

Similarly, if some agents have strong preferences for bonds of particular maturities, then reducing the supply of such bonds (i.e., the local supply) in the hands of the public might make market participants more willing to hold the remaining supply even at lower yields.

In addition, asset purchases can signal to the public that a central bank will keep interest rates low for a long time, as rapid increases in short rates could subject the central bank to embarrassing capital losses on its portfolio (Bhattarai, Eggertsson, and Gafarov, 2015).

Finally, central bank FG can influence current long yields by changing expectations of future short rates. If an announcement leads market participants to expect lower short rates in the future, then—other things equal—bond holders will tend to switch from rolling over short-term positions into holding long bonds. Such rebalancing will also tend to reduce long-term yields.

The Central Banks of Smaller Economies

Some central banks of smaller economies, such as the Swiss National Bank (SNB), the Danish National Bank (DNB), and Swedish Riksbank (the Riksbank), also implemented UMPs in response to the Global Financial Crisis. Consistent with the actions of the Fed, BOE, ECB, and BOJ, these smaller central banks initially expanded their balance sheets by providing emergency liquidity but eventually began large-scale purchases of foreign exchange—not domestic bonds—to weaken their currencies and support real activity.

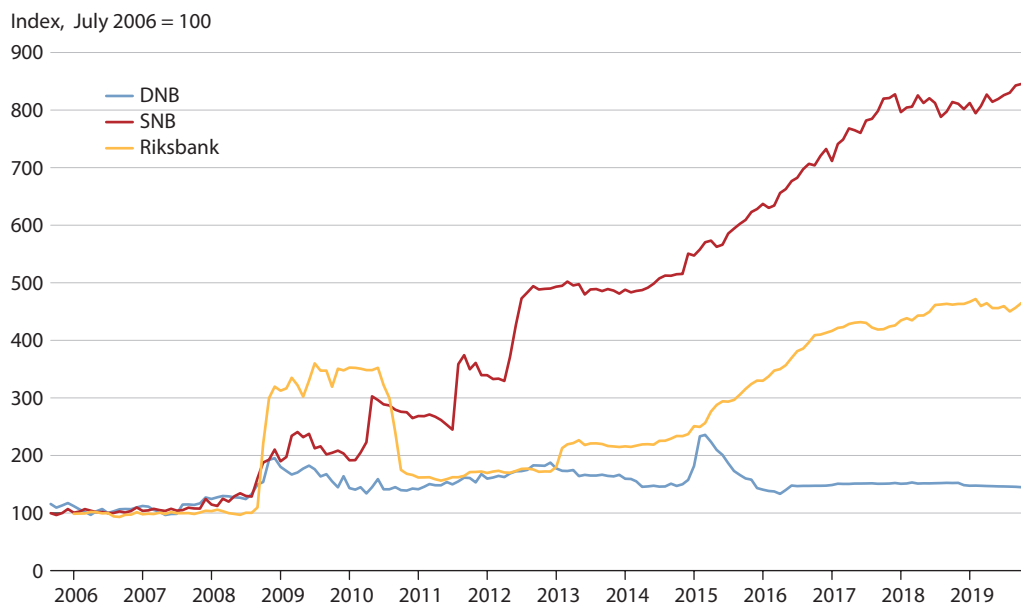
Central banks of smaller economies are generally much more concerned with exchange rates than are major central banks because foreign trade is usually much more important for smaller economies. In addition, foreign exchange markets are typically the deepest and most sophisticated financial markets in small economies, because a small economy would typically have small domestic bond and equity markets. There are exceptions to the focus on exchange rates, however. For example, the Riksbank and the SNB purchased government bonds in a manner like that of the major central banks; that is, they engaged in pure QE. Diez de los Rios and Shamloo (2017), who compare the purchases of the BOE, the Riksbank, and the SNB with those of the Fed, find that the purchases of the three smaller central banks have “limited but significant” effects in lowering bond yields.

Lender of Last Resort Responses to the Financial Crisis

The collapse of the housing bubble in 2006-07 intensely disrupted financial markets and caused the global economy to contract. Concerns about counterparty risk led to funding shortages as banks became reluctant to lend to one another. In December 2007, the SNB made emergency loans to banks in Swiss francs (CHF) and in U.S. dollars (USD) to restore market function with USD obtained through currency swap agreements with the Fed. These lending programs dramatically increased the SNB’s balance sheet, which doubled in size by January 2009 (see figure).

In the wake of the March 2008 Bear Stearns bankruptcy, in May 2008, the DNB also acted as a lender of last resort by providing emergency liquidity through a new short-term liquidity facility. In September 2008, the DNB began providing liquidity in USD through a currency swap agreement with the Fed. These emergency measures increased the size of the DNB’s balance sheet by 50 percent, but it would not rise further over the next few years (see figure).

Assets of Smaller Central Banks



SOURCE: DNB, SNB, and the Riksbank.

The Central Banks of Smaller Economies, cont'd

The Riksbank implemented its own emergency lending programs in September 2008 to counter the severe credit market disturbances that followed the bankruptcy of Lehman Brothers. In addition to supplying liquidity in Swedish krona (SEK), the Riksbank joined other central banks in establishing a currency swap agreement with the Fed to provide USD funding to domestic banks (Anderson, Gascon, and Yang, 2010). The Riksbank also became one of the first monetary authorities to respond to the Financial Crisis with negative deposit rates (−0.25 percent) and with longer-term loans to banks.¹ These longer-term lending facilities increased the size of the Riksbank balance sheet by more than 250 percent at peak, most of which occurred in October 2008. Access to market funding improved in 2010 as indicators of financial stress fell below pre-crisis levels, which prompted the Riksbank to unwind some accommodative policies in the summer of 2010, normalizing its balance sheet.

The Swiss Franc, the Danish Krone, and the European Sovereign Debt Crisis

The SNB was also concerned with international developments, specifically with a flight to safety by international investors that undesirably raised the value of the CHF, which is perceived as exceptionally safe. Fearing that an overvalued CHF would hamper economic activity, beginning in March 2009, the SNB prevented appreciation of its own currency by buying foreign exchange. Such large-scale purchases expanded the SNB's balance sheet by 50 percent by May 2010.

In 2011, the worsening European sovereign debt crisis disrupted financial markets, producing another flight to safety and more upward pressure on the CHF. In August 2011, the SNB responded by purchasing its own bills, expanding sight deposits (i.e., central bank reserves) from CHF 30 billion to CHF 200 billion. Despite this, the CHF continued rising in value. To arrest this rise, on September 6, 2011, the SNB established a currency peg of 1.2 CHF/EUR (euro), which it enforced by first buying foreign exchange and, eventually, by establishing negative interest rates on CHF deposits, which reduced demand for CHF. The SNB maintained this currency peg until the beginning of 2015, at which point it had bought foreign currency worth nearly CHF 250 billion (\$260 billion), equivalent to 40 percent of Switzerland's nominal GDP. As a percentage of GDP, the SNB asset purchases were modestly larger than the value of all new Fed asset purchases. Since abandoning its fixed-exchange-rate policy in 2015, the SNB has continued to actively weaken the CHF, purchasing CHF 280 billion (\$291 billion) of foreign currency between January 2015 and April 2018, expanding its balance sheet by a further 50 percent (see figure).

The SNB's retreat from its currency peg in January 2015 encouraged "massive inflow[s] of speculative money" to Denmark as speculators bet that the ECB would ease further, which would cause the Danish krone (DKK) to appreciate against the EUR.² To defend its own peg to the EUR, the DNB lowered its deposit rate well into negative territory, to −0.75 percent, and began aggressively purchasing EUR.³ Significant currency appreciation would tighten Danish monetary conditions to an unwelcome extent. The DNB purchased DKK 300 billion (\$45 billion) of foreign currency by March 2015, equal to 15 percent of Danish GDP. After market pressures on the DKK subsided by November of 2015, the DNB sold nearly all its recently purchased foreign exchange, returning its balance sheet to pre-crisis levels by 2016.

Sweden Implements QE

Further north, Swedish inflation drifted below the Riksbank's target throughout the second half of 2014 and prompted the central bank to reduce its deposit rate to a negative level, that is, −0.5 percent. On February 12, 2015, the Riksbank announced a negative repo rate, initially −0.1 percent, and that it would begin buying Swedish government bonds—increasing the monetary base—to promote inflation. The Riksbank exclusively purchased bonds with 1 to 25 years of maturity remaining. QE purchases amounted to SEK 340 billion (\$39.8 billion) by the end of 2017, nearly doubling the size of the Riksbank's balance sheet. The Riksbank kept its policy rate anchored at −0.5 percent until December 2018, when rosier economic conditions motivated the central bank to raise the repo rate to −0.25 percent.

Notes

¹ See Molin (2010).

² See Milne (2015).

³ The DNB first set its deposit rate below zero on July 6, 2012, in response to the ECB's decision to lower its deposit rate to the zero lower bound earlier that month.

Central banks have also purchased assets in specific markets to ease credit conditions or reduce particular risk premia in those markets. For example, the first large U.S. asset purchases, announced in November 2008, were of mortgage-backed securities (MBS) to specifically reduce yields in the MBS market by reducing the quantities of specific risks associated with MBS, such as pre-payment risk, and by providing a source of regular liquidity for the market.

Some central banks have extended the bounds of conventional monetary policy by setting negative interest rates on deposits with the central bank (i.e., reserves) or even a negative interest rate on borrowing; that is, they have paid banks to borrow.² Pushing short-term rates below zero has many of the same effects as conventional short-term rate reductions: They both tend to lower yields at all horizons, raise equity and real estate values through discounting, and strengthen balance sheets. Similarly, negative interest rates on excess reserves encourage banks with excess reserves to make loans.

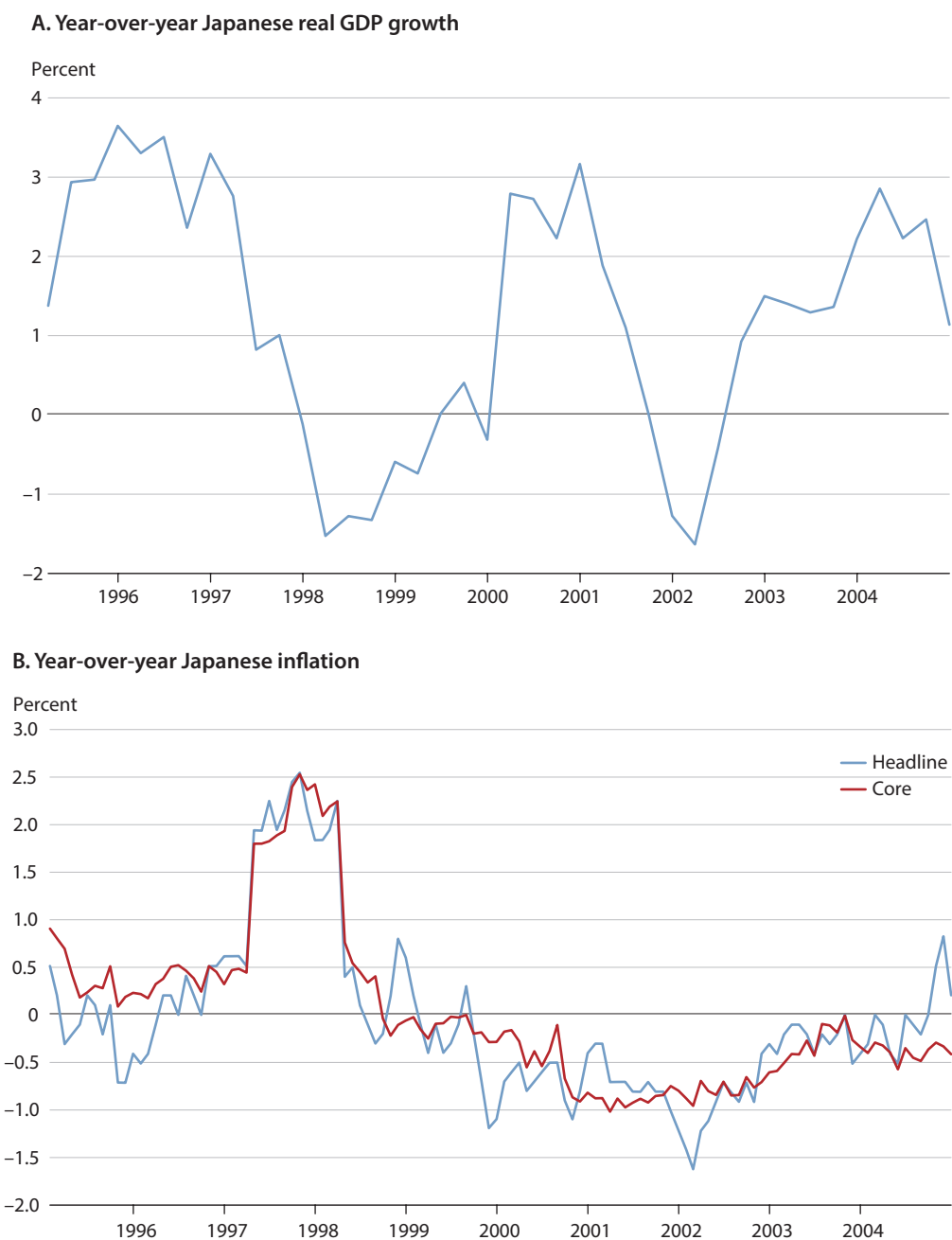
Central banks typically tailor their UMP to the types of intermediation in their economies. In areas where bank intermediation dominates, such as Europe and Japan, central banks have created or altered bank lending programs to support banking markets. For example, after the worst of the 2007-09 Financial Crisis, the BOJ and the ECB supplied liquidity elastically to banks instead of making banks bid for fixed quantities. Since 2012, central banks have developed and expanded conditional bank lending programs that use price or quantity incentives to encourage bank loans to the nonfinancial sector.

Central banks of small, open economies face a different set of challenges than do the major central banks. The former have no control over international monetary conditions; have smaller, more fragmented domestic bond markets; and are more sensitive to international conditions. Therefore, smaller central banks frequently seek to stabilize their exchange rates to facilitate international trade and finance or reset those pegs to influence economic activity. Although commonly used, pegs and foreign exchange intervention might also be considered UMP in the context of developed countries. The boxed insert describes the challenges and unconventional monetary policies of smaller central banks.

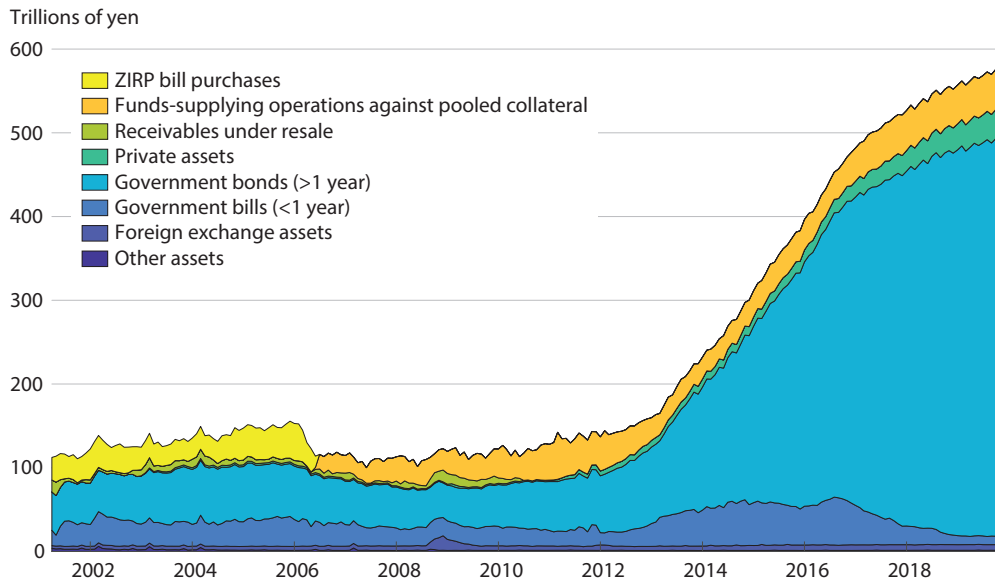
3 A FIRST PASS AT UNCONVENTIONAL MONETARY POLICIES: THE BANK OF JAPAN: 2001-06

The BOJ's 2001-06 response to the severe and prolonged economic downturn known as "the Lost Decade" serves as a recent antecedent to the UMP that followed the Financial Crisis. Japanese asset prices soared to historic highs in the late 1980s as the Japanese economy hummed and the relatively huge cohort of postwar Japanese Baby Boomers invested for their retirements. The Shiller cyclically adjusted price-to-earnings (CAPE) ratio for the Japanese market topped 90 in January 1990. For comparison, the CAPE ratio for the S&P 500 has varied from about 5 to 45 from 1880 to 2020 (Siblis Research, n.d., and Mizrach and Neely, 2020). Japanese equity and real estate prices had become unsustainable and then plunged in the early 1990s, sending the Japanese economy into prolonged stagnation and deflation later in the decade (Figure 1).

From 1991 to 2000, the BOJ responded to this stagnation by repeatedly lowering its conventional policy rate. The Japanese authority also employed some FG on April 13, 1999,

Figure 1**Japanese Economic Performance, 1995-2004**

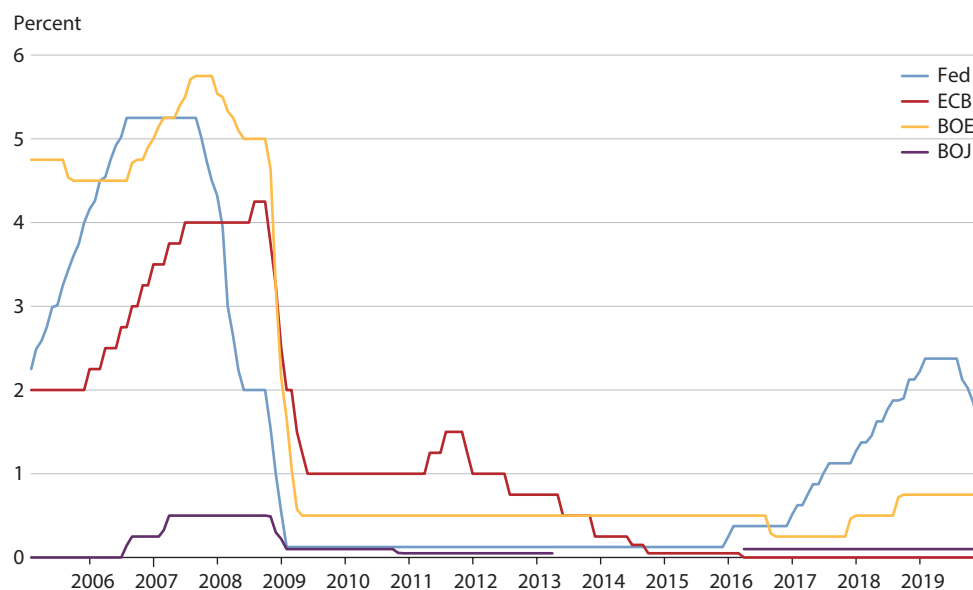
SOURCE: Haver Analytics and Organisation for Economic Co-operation and Development.

Figure 2**BOJ Assets, 2001-19**

NOTE: "Government bonds" includes monthly JGB purchases. "ZIRP bill purchases" includes public debt purchases made under Japan's ZIRP as part of its QE program in the early 2000s but excludes monthly JGB purchases. "Private assets" includes all purchases of commercial paper, commercial bonds, ETFs, J-REITs, stocks, and MBS. On June 26, 2006, the BOJ introduced new electronic operations (funds-supplying operations against pooled collateral) to replace conventional paper-based bill purchasing operations. Holdings of the GSFF and SBLF are included in "Funds-supplying operations against pooled collateral."

SOURCE: BOJ.

promising essentially zero interbank interest rates until deflationary concerns subsided.³ Dissatisfied with the results of this zero interest rate policy (ZIRP), the BOJ turned to UMP on March 19, 2001, switching its main policy instrument from the uncollateralized overnight call rate to the quantity of reserves held by financial institutions with the central bank.⁴ The BOJ initially targeted bank reserves at ¥5 trillion (\$41 billion), an increase of roughly ¥1 trillion (\$7 billion) from previous levels and stated that it would maintain its accommodative policy until inflation—which had been significantly negative—firmly reached 0 percent.⁵ The BOJ purchased long-term Japanese government bonds (JGBs) and asset-backed securities (ABS) to reach its reserves target, which increased nine times over the next four years, ultimately reaching a target range of ¥30 to ¥35 trillion (\$247 to \$288 billion). The expansion of the BOJ's balance sheet reflects the progressive increases in reserve targets over this span (Figure 2).⁶ Bank reserves were a very small part of the Japanese monetary base, which consisted largely of currency, so this policy produced only a small percentage increase in that base.⁷ The BOJ supplemented these asset purchases with another promise, on October 10, 2003, to maintain QE until inflation was "stably" nonnegative (BOJ, 2003). On March 9, 2006, the BOJ ended this UMP by announcing a return to using the uncollateralized overnight interest rate as its

Figure 3**Central Bank Policy Rates**

NOTE: The key policy rates for the Fed, ECB, BOE, and BOJ are, respectively, the federal funds target rate, the main refinancing operations rate, the official bank rate, and the uncollateralized overnight call rate. Between April 2013 and February 2016, the BOJ did not set a target for the uncollateralized overnight call rate. Starting in March 2016, the BOJ resumed targeting a short-term interest rate, for which we report the BOJ's basic balance rate.

SOURCE: Fed, ECB, BOE, and BOJ.

main monetary policy tool, but it continued purchasing JGBs at a pace of ¥1.2 trillion (\$10 billion) per month.

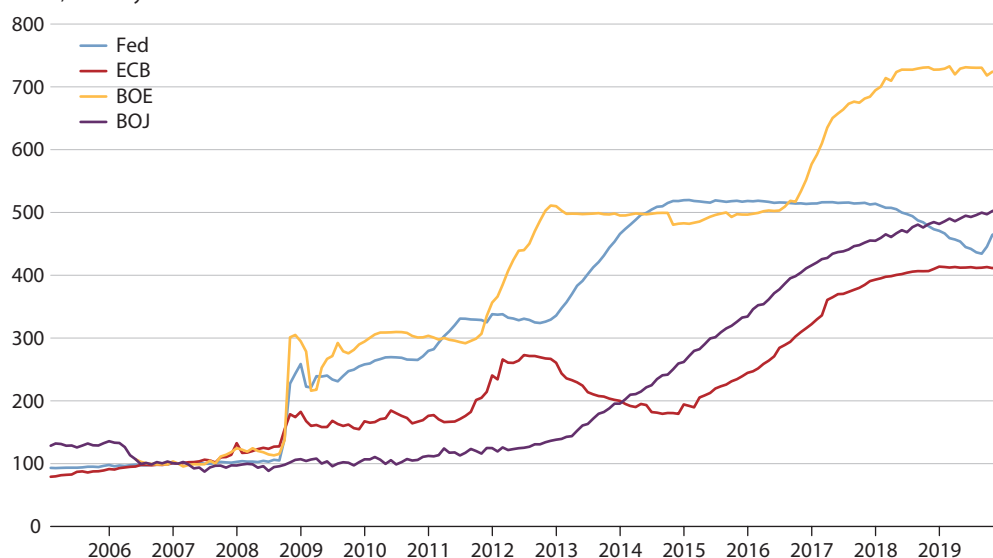
With the benefit of hindsight, the promise to maintain UMP until inflation was positive for a few consecutive months appears to have been much too unambitious. Malmendier and Nagel (2016) argue that people overweight inflation experienced during their lifetimes when forming expectations. Thus, the long period of Japanese deflation would produce persistently low inflation expectations. In later years, the BOJ would adopt progressively more ambitious inflation targets to attempt to break such beliefs.

4 RESPONSES TO THE GLOBAL FINANCIAL CRISIS: 2008-12

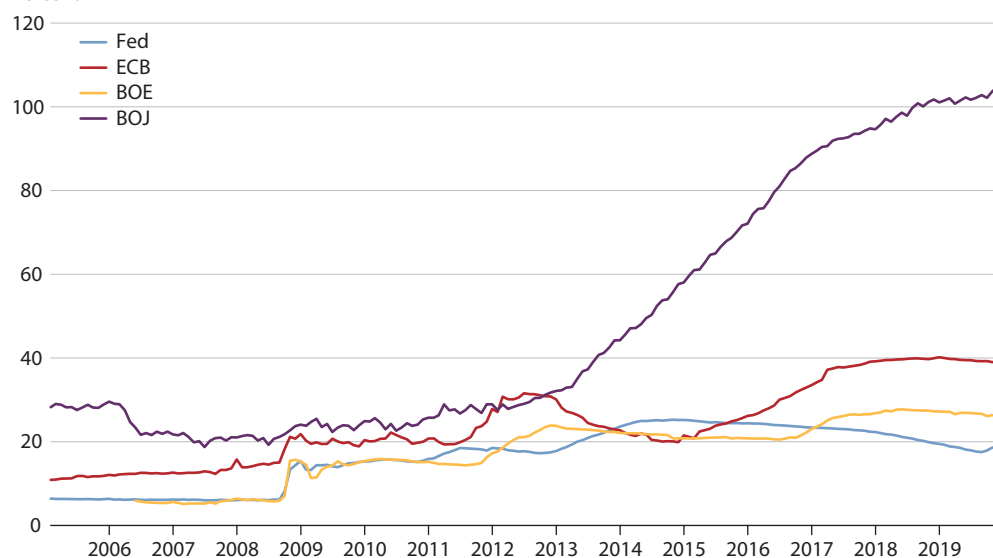
The collapse of the housing bubble in 2006-07 sparked a financial crisis and a global contraction in real activity—the Great Recession. Monetary authorities initially focused on emergency lending to restore financial market functions but quickly shifted to staving off deflation and stimulating economic activity by cutting policy rates (Figure 3), later supplementing those conventional cuts with large-scale asset purchases (LSAPs) and long-term lending programs (Figure 4).

Figure 4**Central Bank Assets****A. Normalized central bank assets**

Index, January 2007 = 100

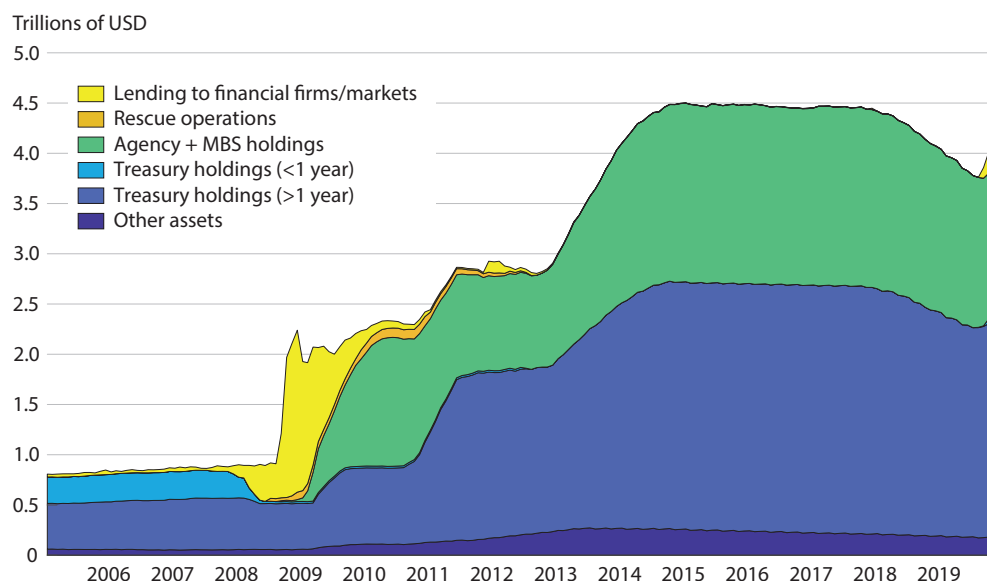
**B. Central bank assets as a percentage of GDP**

Percent



NOTE: Panel A shows the monetary bases of the United States, European Monetary System, United Kingdom, and Japan, normalized to equal 100 in January 2007. Panel B shows the monetary bases of the United States, the European Monetary System, the United Kingdom, and Japan, each as a percentage of their respective nominal GDP.

SOURCE: Fed, ECB, BOE, and BOJ.

Figure 5**Fed Assets**

NOTE: "Lending to financial firms and markets" includes repurchase agreements, term auction credit, the CPFF, central bank liquidity swaps, the MMIFF, other loans, and the Term Asset-Backed Securities Loan Facility. "Rescue operations" includes net portfolio holdings of Maiden Lanes I, II, and III and preferred interests in AIA Aurora and ALICO Holdings. The figure shows the accumulation of agency and MBS holdings on the Fed balance sheet beginning in November 2008 and long-term Treasury securities beginning in March 2009. Fed balance sheet holdings begin declining in late 2017 as a result of the Fed's Policy Normalization Plan. The increase in asset holdings in late 2019 reflects technical measures implemented by the Fed in money markets to ensure effective policy implementation and do not indicate a change in the stance of monetary policy.

SOURCE: Fed and Haver Analytics.

4.1 The Federal Reserve: 2008-12

In 2008, the Federal Open Market Committee (FOMC) became increasingly concerned about the functioning of credit markets and the danger of systemic risk to the economy (Bullard, Neely, and Wheelock, 2009). In response, the Fed created several facilities to support credit markets.⁸ Some of these programs directly lent to banks or purchased private assets (e.g., commercial paper) to provide liquidity to targeted markets. These programs included both Fed discount window loans and also special loans, such as the \$85 billion loan to American International Group (AIG).⁹ These unsterilized policy measures constituted the first unusual expansion of the Fed's balance sheet in September 2008, which can be seen as the first steep rise in Fed assets shown in Figure 5.

On the heels of this emergency lending, the Fed began the first of four LSAP programs to stimulate U.S. economic activity and promote price stability. The FOMC announced the two components of this first round of QE (QE1), on November 25, 2008, and March 18, 2009, respectively. QE1 eventually purchased \$1.725 trillion in federal housing agency debt, private

MBS, and Treasuries. The Fed designed QE1 to support housing sales and construction, which had been hit hard by the 2006-08 fall in real estate prices and the subsequent Financial Crisis. Housing government sponsored enterprise (GSE) debt and MBS accounted for more than 80 percent of the \$1.725 trillion in purchased assets. The FOMC paired QE1 with forward guidance, suggesting that it would keep the federal funds rate lower “for some time” (Fed, 2008) and “for an extended period” (Fed, 2009).¹⁰ The Fed then purchased \$600 billion of longer-term Treasuries under QE2 during 2010-11. In late 2011, the Fed introduced the Maturity Extension Program (MEP)—nicknamed “Operation Twist”—which funded purchases of long-term Treasury notes through equal sales of short-term Treasury bills. In June 2012, the FOMC responded to stubbornly weak labor market conditions by extending the MEP to December 2012. In September 2012, the FOMC announced a third round of outright asset purchases (QE3), under which it purchased \$40 billion in MBS each month, indefinitely, again with housing markets in mind. In December 2012, the Fed announced it would add \$45 billion per month in Treasury purchases to the existing QE3 MBS purchases. Bond purchases comprised a very important part of the Fed’s UMP, reflecting the importance of bond markets in the U.S. economy (Bini Smaghi, 2009).

4.2 *The Bank of England: 2008-12*

Facing financial and economic circumstances like those in the United States, the BOE began its unconventional policies on January 19, 2009, by announcing an asset purchase facility (APF) that would buy £50 billion (\$78 billion) in commercial paper and corporate bonds. The BOE soon increased APF purchases to £200 billion (\$314 billion), targeting medium and long-term gilts to drive down those yields and to provide broad monetary stimulus. The BOE’s APF initially financed these purchases by issuing short-term gilts, which did not change the monetary base, but switched to issuing reserves to fund purchases in March 2009, which more than doubled the U.K. monetary base by the end of 2009. Like the Fed, the BOE conditioned its asset purchases on economic circumstances. In response to the worsening European sovereign debt crisis, the BOE started a second round of asset purchases in late-2011 and raised its APF ceiling to £275 billion (\$436 billion). The APF held £375 billion (\$594 billion) in assets at the end of 2012, mostly in U.K. government bonds. Although the BOE authorized up to £10 billion (\$15.9 billion) in private asset purchases, the APF didn’t hold more than £3 billion (\$4.8 billion) of that class at the end of 2012.

4.3 *The European Central Bank: 2008-12*

Prior to 2013, the ECB implemented a comparatively modest UMP program that focused on providing liquidity to banks and supporting sovereign bond markets in the face of default fears. The ECB did not ease policy as quickly or drastically as the Fed and BOE because it was more concerned about the upside risks to inflation—which had climbed to 4 percent—and more skeptical of the risks to financial stability. Indeed, when the Financial Crisis came to a head in September 2008, the ECB had been raising short-term interest rates for several years and it waited until October 8, 2008, almost a month after the Lehman Brothers’ bankruptcy filing, to make its initial interest rate reduction in response to the crisis. One week after that

initial cut, on October 15, 2008, the ECB pledged to make unlimited fixed-rate loans to banks to ensure “continued access to liquidity” (González-Páramo, 2011), a policy known as fixed-rate full allotment (FRFA). This policy naturally increased reserves during periods of illiquidity, but only banks with adequate collateral could bid for loans, which controlled the expansion.

The ECB employed a second, complementary strategy to support the covered bond market, an important funding source for banks. The ECB announced its first program to purchase assets on May 7, 2009, the covered bond purchase program (CBPP), which acquired €60 billion (\$83.4 billion) in covered bonds. The bank bought an additional €40 billion (\$55.6 billion) in 2011 (CBPP2). Buying covered bonds allowed the ECB to indirectly lend to banks, ensuring funding for them.

In contrast to the Fed’s and BOE’s emphasis on bond purchases, the ECB focused on supporting the banking system because of the relative importance of banking credit in the euro area compared with its importance in the United States or United Kingdom, where bond markets are more important. In 2016, for example, the U.S. bond market grew to \$36 trillion in outstanding debt securities, compared with \$18 trillion for the euro area bond market.¹¹ That is, outstanding U.S. debt securities expanded to 193 percent of U.S. gross domestic product (GDP), while the euro area debt securities only reached 153 percent of euro area GDP.

European governments generally responded to the Financial Crisis with bank recapitalization programs and fiscal stimulus. Some countries, such as Portugal, Ireland, Italy, Greece, and Spain, carried preexisting, large sovereign debts that became very difficult to sustain due to the deficit spending demanded by the crisis. In 2009-10, ratings agencies downgraded the credit ratings of the sovereign bonds of those stressed nations, which helped erode already sinking investor confidence. The bond yields of these euro area nations soared as creditors feared that a single sovereign default could force a costly bailout from the European Union, a financial crisis, and a domino effect on other euro area nations.

The escalating European sovereign debt crisis prompted the ECB to introduce the Securities Markets Program (SMP) in May 2010 to purchase government debt and thereby promote depth and liquidity in the troubled sovereign-debt markets. The ECB funded SMP purchases with sales of other assets to prevent those transactions from increasing the money supply. That is, the ECB *sterilized* its SMP purchases. The SMP accumulated €220 billion (\$293 billion) in euro area sovereign debt at its peak.

In September 2012, the ECB replaced the SMP with the Outright Monetary Transactions (OMTs) program. In contrast to the SMP, a government wishing to have its bonds purchased under the OMT program must submit a plan for fiscal consolidation and financial reforms subject to the European Stability Mechanism (ESM). While the ECB has not exercised OMTs, policymakers argued that the OMTs announcement quelled fears of a euro area dissolution, shrank distortions in sovereign debt markets, and ultimately reduced the risk that an OMT intervention would be necessary (Cœuré, 2013). Altavilla, Giannone, and Lenza (2016) find that OMT announcements cumulatively reduced two-year yields by 200 basis points for the most stressed nations, such as Italy and Spain.

Table 1**Bank of Japan Holdings as of December 2012**

Asset type	BOJ APP holdings (trillion yen)	BOJ APP holdings (percent of holdings)
JGBs	24.0	60.0
T-bills	9.5	23.8
Commercial paper	2.1	5.3
Corporate bonds	2.9	7.3
ETFs	1.6	4.0
J-REITS	0.1	0.3
Total	40.0	100.00

NOTE: This table details the distribution of BOJ APP holdings by asset class as of December 2012. Columns may not sum to totals due to rounding.

SOURCE: BOJ.

4.4 The Bank of Japan: 2008-12

Like other major central banks, the BOJ acted as a lender of last resort during the extreme financial market turmoil of the latter half of 2008. Specifically, on December 2, 2008, the BOJ announced that it would begin special funds-supplying operations (SFSOs) that—like the ECB’s FRFA operations—offered unlimited, low-interest loans to banks in exchange for collateral. As in the ECB’s case, the BOJ’s policies reflected the central role that banks play in the Japanese economy.

The BOJ complemented its lending operations by purchasing public and private assets. From December 2008 through February 2009, the BOJ raised its monthly JGB purchases from ¥1.2 to ¥1.4 trillion (\$12.8 billion to \$14.9 billion) and announced plans to purchase ¥4 trillion (\$42.7 billion) in private assets, such as high-quality commercial paper and corporate bonds, to lower the premium on private borrowing costs. These amounts were quite modest in comparison with Fed asset purchases, even when adjusted for the relative sizes of the economies.

As with other central banks, the BOJ soon broadened its focus from supporting financial markets to promoting growth and price stability. On May 21, 2010, the BOJ introduced the Growth-Supporting Funding Facility (GSFF), a lending program that offered up to ¥3 trillion (\$34.2 billion) in low-cost loans to support new businesses, technological research, and social infrastructure such as medical facilities, universities, and housing. In October 2010, the BOJ again promised zero interest rates until “price stability is in sight” and it established an asset purchase program (APP) to buy a range of public and private assets to ease monetary policy further (BOJ, 2010).¹² The BOJ APP had accumulated ¥40 trillion (\$501 billion) in public and private assets by the end of 2012 (see Table 1 for a breakdown by asset class) and planned to purchase another ¥36 trillion (\$369 billion) in assets throughout 2013. These plans would soon be revised, however.

In 2011, the BOJ provided emergency liquidity in response to a new crisis: the Tōhoku earthquake of March 11, 2011, which killed over 15,000 people and caused from \$117 to \$306 billion in property damage (Kazama and Noda, 2012). The disaster also sparked widespread volatility in financial markets. The BOJ responded by lending through its Funds-Supplying Operations to Support Financial Institutions in Disaster Areas program. This emergency lending facility offered ¥1 trillion (\$12.5 billion) of low-interest rate loans to banks with business operations in affected areas.

The yen appreciated sharply in the wake of the earthquake as “carry trade” investors closed borrowing positions in the yen and market participants anticipated that insurance companies would repatriate reserves from abroad. To counter this yen appreciation, the G-7 authorities jointly intervened to sell yen, which weakened the currency as much as 4 percent (see Neely, 2011).

Although Japan adopted UMP early, its efforts in 2001-06 and 2008-12 seem cautious by some metrics in comparison with those of its peer institutions. The BOJ brought about the smallest percentage increase in its assets among the four major central banks during 2008-12. Over those four years, the BOJ’s holdings grew by 40 percent, in contrast to the larger increases engineered by the Fed (223 percent), BOE (317 percent), and ECB (123 percent). However, this comparison is sensitive to the metric. If one considers the change in central bank holdings as a fraction of GDP—rather than as a fraction of central bank assets—the BOJ expanded its balance sheet from 21 percent to 32 percent of GDP, an 11 percentage point increase, which is similar to the Fed’s increase (12 percentage points) and modestly smaller than those of the BOE (18 percentage points) and the ECB (16 percentage points). The GDP comparison is probably more appropriate, as the initial central bank asset holdings depend on factors such as the proportion of currency held in the economy.

An additional complication in drawing such comparisons is that financial and economic conditions differed among the major economies. For example, the Financial Crisis was less severe in Japan than in the United States, but the decline in Japanese GDP was more severe and unwelcome deflation more persistent. Thus, it is not easy to judge definitively, even in hindsight, whether the BOJ expanded more or less than other central banks or whether it should have attempted to do so.

5 UNCONVENTIONAL MONETARY POLICIES EVOLVE: 2012-15

During 2008-12, central banks used a variety of UMPs to stimulate economic activity and achieve price stability. Research and experience with these policies led policymakers to modify such policies and introduce new variations. In particular, central banks began conditioning asset purchases explicitly on incoming data—making the purchases contingent and open-ended—and modifying bank lending programs to provide incentives for banks to expand their lending to the nonfinancial economy.

Table 2A

Federal Reserve

Date	Program	Event (link)	Brief description	Interest rate news
11/25/2008	QE1	FOMC statement	LSAPs announced: Fed will purchase \$100 billion in GSE debt and \$500 billion in MBS.	
12/1/2008	QE1	Bernanke speech	First suggestion of extending QE to Treasuries.	
12/16/2008	QE1	FOMC statement	First suggestion of extending QE to Treasuries by FOMC.	Federal funds target rate lowered from 1% to 0-0.25%; Fed expects low rates "for some time."
1/28/2009	QE1	FOMC statement	Fed stands ready to expand QE and buy Treasuries.	
3/18/2009	QE1	FOMC statement	LSAPs expanded: Fed to purchase \$300 billion in long-term Treasuries and another \$750 billion and \$100 billion in MBS and GSE debt, respectively.	Fed expects low rates for "an extended period."
8/12/2009	QE1	FOMC statement	LSAPs slowed: All purchases will finish by the end of October, not mid-September.	
9/23/2009	QE1	FOMC statement	LSAPs slowed: Agency debt and MBS purchases will finish at the end of 2010:Q1.	
11/4/2009	QE1	FOMC statement	LSAPs downsized: Agency debt purchases will finish at \$175 billion.	
8/10/2010	QE1	FOMC statement	Balance sheet maintained: The Fed will reinvest principal payments from LSAPs in Treasuries.	
8/27/2010	QE2	Bernanke speech	Chairman Bernanke suggests role for additional QE "should further action prove necessary."	
9/21/2010	QE2	FOMC statement	FOMC emphasizes low inflation, which "is likely to remain subdued for some time."	
10/12/2010	QE2	FOMC minutes released	FOMC members' "sense" is that "[additional] accommodation may be appropriate before long."	
10/15/2010	QE2	Bernanke speech	Bernanke reiterates that the Fed stands ready to further ease policy.	
11/3/2010	QE2	FOMC statement	QE2 announced: Fed will purchase \$600 billion in Treasuries.	
6/22/2011	QE2	FOMC statement	QE2 finishes: Treasury purchases will wrap up at the end of month, as scheduled; principal payments will continue to be reinvested.	
9/21/2011	MEP	FOMC statement	Maturity Extension Program ("MEP") announced: Fed to purchase \$400 billion of Treasuries with remaining maturities of 6-30 years and sell an equal amount of short-term Treasuries; MBS and agency debt principal payments will no longer be reinvested in Treasuries but instead in MBS.	
6/20/2012	MEP	FOMC statement	MEP extended: Fed to continue purchasing long-term securities and selling short-term securities through 2012. Purchases/sales will continue at the current pace, about \$45 billion/month.	
8/22/2012	QE3	FOMC minutes released	FOMC members "judged that additional monetary accommodation would likely be warranted fairly soon."	
9/13/2012	QE3	FOMC statement	QE3 announced: Fed will purchase \$40 billion of MBS per month as long as "the outlook for the labor market does not improve substantially...in a context of price stability."	Fed expects low rates "at least through mid-2015."

Table 2A, cont'd
Federal Reserve

Date	Program	Event (link)	Brief description	Interest rate news
12/12/2012	QE3	FOMC statement	QE3 expanded: Fed will continue to purchase \$45 billion of long-term Treasuries per month but will no longer sterilize purchases through the sale of short-term Treasuries.	Fed expects low rates to be appropriate while unemployment is above 6.5% and inflation is forecasted below 2.5%.
6/19/2013	QE3	FOMC statement	FOMC "currently anticipates that it would be appropriate to moderate the monthly pace of purchases later this year," according to Chairman Bernanke's press conference.	
12/18/2013	QE3	FOMC statement	QE3 downsized: Beginning in January, Fed will make monthly purchases of \$35 billion in MBS and \$40 billion in Treasuries, down from \$40 billion and \$45 billion, respectively.	Fed expects low rates "well past the time that the unemployment rate declines below 6.5 percent."
1/29/2014	QE3	FOMC statement	QE3 downsized: Fed reduces monthly asset purchases to \$30 billion in MBS and \$35 billion in Treasuries.	
3/19/2014	QE3	FOMC statement	QE3 downsized: Fed reduces monthly asset purchases to \$25 billion in MBS and \$30 billion in Treasuries.	Fed expects low rates "for a considerable time after the asset purchase program ends."
4/30/2014	QE3	FOMC statement	QE3 downsized: Fed reduces monthly asset purchases to \$20 billion in MBS and \$25 billion in Treasuries.	
6/18/2014	QE3	FOMC statement	QE3 downsized: Fed reduces monthly asset purchases to \$15 billion in MBS and \$20 billion in Treasuries.	
7/30/2014	QE3	FOMC statement	QE3 downsized: Fed reduces monthly asset purchases to \$10 billion in MBS and \$15 billion in Treasuries.	
9/17/2014	QE3	FOMC statement	QE3 downsized: Fed reduces monthly asset purchases to \$5 billion in MBS and \$10 billion in Treasuries. FOMC releases initial normalization principles.	
10/29/2014	QE3	FOMC statement	QE3 finishes: Fed officially concludes QE3 and will continue to re-invest principal payments from its LSAPs in Treasuries.	
6/14/2017	Balance sheet normalization	Addendum to policy normalization plan	FOMC announces normalization plans: Fed to allow assets to mature without reinvesting principal payments and, instead, will retire those monies. The Fed will first retire a maximum of \$6 billion (\$4 billion) from principal payments of Treasuries (MBS and agency debt) each month and will raise the cap by \$6 billion (\$4 billion) every quarter for a year.	Federal funds target rate range raised from 0.75-1.00% to 1.00-1.25%.
9/20/2017	Balance sheet normalization	FOMC statement	Starting in October 2017, Fed will initiate the balance sheet normalization program described at its meeting in June 2017.	
3/21/2018	NA	FOMC statement	NA	Federal funds target rate range raised to 1.5-1.75%.
6/13/2018	NA	FOMC statement	NA	Federal funds target rate range raised to 1.75-2%.
9/26/2018	NA	FOMC statement	NA	Federal funds target rate range raised to 2-2.25%.

Table 2A, cont'd
Federal Reserve

Date	Program	Event (link)	Brief description	Interest rate news
12/19/2018	NA	FOMC statement	NA	Federal funds target rate range raised to 2.25-2.5%.
1/30/2019	Balance sheet normalization	FOMC supplemental statement	FOMC specifies its intention to operate in a regime with an ample supply of reserves that does not require active management; says it is prepared to adjust details of balance sheet normalization in light of changes to economic conditions.	
3/20/2019	Balance sheet normalization	FOMC supplemental statement	FOMC intends to slow pace of decline in reserves over coming quarters: Will slow reduction of Treasuries by reducing cap on monthly redemptions from \$30 billion to \$15 billion in May 2019; will conclude reduction of aggregate securities holdings in the System Open Market Account at end of September 2019; will continue to allow agency and MBS security holdings to decline, reinvesting principal payments from such securities in Treasuries up to \$20 billion per month starting in October 2019.	
7/31/2019	Balance sheet normalization	FOMC statement	FOMC announces conclusion of balance sheet shrinking program (two months earlier than anticipated).	Federal funds target rate range lowered to 2-2.25%
9/18/2019	NA	FOMC statement	NA	Federal funds target rate range lowered to 1.75-2%.
10/11/2019	Balance sheet normalization, repos	FOMC supplemental statement	FOMC announces Fed will purchase Treasury bills at least into 2020: Q2 to maintain ample reserve balances; will conduct term and overnight repo agreement operations at least through January 2020 to ensure ample reserve supply and to mitigate risk of money market pressures.	

Table 2B

European Central Bank

Date	Program	Event (link)	Brief description	Interest rate news
3/28/2008	LTRO	Governing Council press release	LTRO expanded: 6-month LTROs announced.	
10/15/2008	FRFA	Governing Council press release	Refinancing operations expanded: All refinancing operations will be conducted with fixed-rate tenders and full allotment; the list of assets eligible as collateral in credit operations with the Bank is expanded to included lower-rated (with the exception of ABS) and non-euro-denominated assets.	
3/5/2009	NA	Governing Council press release	NA	MRO rate lowered to 1.5%; marginal lending facility (MLF) rate lowered to 2.5%; deposit facility rate (DFR) lowered to 0.5%.
4/2/2009	NA	Governing Council press release	NA	MRO rate lowered to 1.25%; MLF rate lowered to 2.25%; DFR lowered to 0.25%.
5/7/2009	CBPP, LTRO	Governing Council press release	CBPP announced/LTRO expanded: ECB to purchase €60 billion in euro-denominated covered bonds; 12-month LTRO announced.	MRO rate lowered to 1%; MLF rate lowered to 1.75%.
5/10/2010	SMP	Governing Council press release	SMP announced: The ECB will conduct interventions in the euro area public and private debt securities markets; purchases will be sterilized.	
6/30/2010	CBPP	Governing Council press release	CBPP finished: Purchases finish on schedule; bonds purchased will be held through maturity.	
10/6/2011	CBPP2	Governing Council press release	CBPP2 announced: ECB to purchase €40 billion in euro-denominated covered bonds.	
12/8/2011	LTRO	Governing Council press release	LTRO expanded: 36-month LTRO are announced; eligible collateral is expanded.	MRO rate lowered to 1%; MLF rate lowered to 1.75%; DFR lowered to 0%.
8/2/2012	OMT	ECB press conference	ECB President Draghi indicates that the ECB will expand sovereign debt purchases. He proclaims that "the euro is irreversible."	
9/6/2012	OMT	Governing Council press release	OMT's announced: Countries that apply to the ESM for aid and abide by its terms will be eligible to have their debt purchased in unlimited amounts on the secondary market by the ECB.	
10/31/2012	CBPP2	Governing Council press release	As scheduled, asset purchases under CBPP2 conclude.	
5/2/2013	NA	Governing Council press release	NA	MRO rate lowered to 0.5%; MLF rate lowered to 1.0%; DFR unchanged.
11/7/2013	NA	Governing Council press release	NA	MRO rate lowered to 0.25%; MLF rate lowered to 0.75%; DFR unchanged.

Table 2B, cont'd
European Central Bank

Date	Program	Event (link)	Brief description	Interest rate news
6/5/2014	TLTRO	Governing Council press release	TLTRO announced: ECB to provide low-interest loans at four-year maturities. TLTRO will incorporate incentives to encourage banks to lend to the real economy. ECB accelerating preparations for outright purchases of ABS.	MRO rate lowered to 0.15%; MLF rate lowered to 0.4%; DFR lowered to -0.1%. Interest rates "will remain at present levels for an extended period."
9/4/2014	ABSPP, CBPP3	Governing Council press release	ECB's APP will purchase "simple and transparent" ABS and covered bonds through the ABSPP and CBPP3.	MRO rate lowered to 0.05%; MLF rate lowered to 0.3%; DFR lowered to -0.2%.
9/18/2014	TLTRO	Governing Council press release	ECB allots €82.6 billion in first round of TLTROs.	
10/2/2014	ABSPP, CBPP3	Governing Council press release	ABSPP and CBPP3 will begin purchases in 2014:Q4 and run for 2+ years. Programs will have a "sizeable impact" on the balance sheet.	
11/6/2014	ABSPP, CBPP3	Governing Council press release	Draghi states that ABSPP and CBPP3 will grow the balance sheet "towards the dimensions it had at the beginning of 2012."	
1/22/2015	APP, TLTRO	Governing Council press release	ECB announces the PSPP, which will purchase bonds from euro area central governments. APP to buy €60 billion in assets per month until at least September 2016. ECB eliminates the 10-basis-point spread on TLTRO above the MRO rate.	
12/3/2015	APP	Governing Council press release	APP extended until March 2017, or beyond, and will also purchase debt of regional and local euro area governments. ECB to reinvest principal payments from holdings.	DFR lowered to -0.3%.
3/10/2016	TLTRO II, APP	Governing Council press release	APP expanded: ECB announces the CSPP, which will purchase corporate bonds. APP will purchase €80 billion in assets per month until at least March 2017. TLTRO II announced: a new long-term lending program offering lower interest rates to banks that increase lending activity.	MRO rate lowered to 0%; MLF rate lowered to 0.25%; DFR lowered to -0.4%. ECB expects rates at current or lower levels "well past the horizon of net asset purchases."
4/21/2016	APP	Governing Council press release	Announces that corporate bond purchases must (i) be rated BBB- or higher, (ii) have between 6 months and 30 years of maturity remaining, and (iii) be issued by a corporation incorporated in the euro area.	
6/8/2016	APP	Governing Council press release	CSPP purchases commence.	
12/8/2016	APP	Governing Council press release	APP downsized: ECB will reduce monthly asset purchases from €80 billion to €60 billion starting in April 2017 until December 2017, or beyond, if necessary.	
4/27/2017	APP	Governing Council press release	ECB confirms that APP monthly asset purchases will proceed at €60 billion.	
10/26/2017	APP	Governing Council press release	APP downsized: ECB to purchase €30 billion in assets each month starting January 2018 until September 2018, or beyond if necessary. The ECB will also continue its FRFA policy until 2019 at least.	

Table 2B, cont'd
European Central Bank

Date	Program	Event (link)	Brief description	Interest rate news
6/14/2018	APP	Governing Council press release	APP downsized: ECB to purchase €15 billion in assets each month starting in September 2018 until December 2018, at which point it will end net purchases. ECB to continue reinvesting principal payments. Policies conditional on a “sustained convergence of inflation.”	ECB expects rates to be at “present levels at least through the summer of 2019” and as long as necessary to ensure inflation remains aligned with a sustained adjustment path.
12/13/2018	APP	Governing Council press release	ECB intends to continue reinvesting principal from securities purchased under the APP for an extended period of time past the date when it starts raising key ECB interest rates.	
3/7/2019	TLTRO III	Governing Council press release	TLTRO III announced, starting in September 2019 and ending in March 2021, with loan maturities of two years. Counterparties can borrow up to 30% of the stock of eligible loans.	
9/12/2019	APP, TLTRO III	Governing Council press release	ECB announces changes to TLTRO III: Interest rate will be reduced, will be equal to the MRO, and can be lower depending on net lending. Maturity of operations extended to three years. ECB restarts net purchases under APP at a €20 billion monthly pace; expects them to run for as long as necessary to reinforce the accommodative impact of its policy rates and to end shortly before it starts raising the key ECB interest rates.	DFR lowered to –0.5%.

Table 2C

Bank of England

Date	Program	Event (link)	Brief description	Interest rate news
1/19/2009	APF	Her Majesty's (HM) Treasury statement	APF established: BOE to purchase up to £50 billion of "high quality private sector assets" financed by Treasury issuance.	
2/11/2009	APF	BOE Inflation Report released	BOE views a slight downside risk to meeting the inflation target, reiterates use of APF as a potential policy instrument.	
3/5/2009	APF	MPC statement	QE announced: BOE will purchase up to £75 billion in assets, now financed by reserve issuance; medium- and long-term gilts will comprise the "majority" of new purchases.	Bank rate reduced from 1% to 0.5%.
5/7/2009	APF	MPC statement	QE expanded: BOE to purchase up to £125 billion in assets.	
8/6/2009	APF	MPC statement	QE expanded: BOE to purchase up to £175 billion in assets; to accommodate increased size, BOE will expand purchases into gilts with remaining maturity of 3 years or more.	
11/5/2009	APF	MPC statement	QE expanded: BOE to purchase up to £200 billion in assets.	
2/4/2010	APF	MPC statement	QE maintained: BOE to maintain the stock of asset purchases financed by the issuance of reserves at £200 billion; new purchases of private assets will be financed by Treasury issuance.	
10/6/2011	APF	MPC statement	QE expanded: BOE to purchase up to £275 billion in assets financed by reserve issuance; the ceiling on private assets held remains £50 billion.	
11/29/2011	APF	HM Treasury decision	Maximum private asset purchases reduced: HM Treasury lowers the ceiling on APF private asset holdings from £50 billion to £10 billion.	
2/9/2012	APF	MPC statement	QE expanded: BOE to purchase up to £325 billion in assets.	
7/5/2012	APF	MPC statement	QE expanded: BOE to purchase up to £375 billion in assets.	
7/13/2012	FLS	News release	FLS announced: Program will lend Treasury bills to banks for up to four years to use as collateral in money markets. Lending program includes interest rate and borrowing quantity incentives to encourage banks to increase lending activity. Program will expire in January 2014.	
4/24/2013	FLS	News release	FLS modified: BOE extends FLS until January 2015 and increases incentives for lending to SMEs.	
11/28/2013	FLS	News release	FLS modified: Following January 2014, BOE will remove special incentives for lending to households. BOE will also eliminate variable interest rate on FLS drawings and banks will pay 25-basis-points flat fee on funds borrowed.	
12/2/2014	FLS	News release	FLS modified: BOE extends FLS until January 2016 and removes special incentives for lending to large corporations.	
11/30/2015	FLS	News release	FLS extended: Starting in August 2016, banks' borrowing allowances will be reduced by 25% every six months until the end of January 2018 when the FLS will close.	

Table 2C, cont'd
Bank of England

Date	Program	Event (link)	Brief description	Interest rate news
8/4/2016	APF	MP statement	QE expanded: BOE announces purchases of £10 billion in UK corporate bonds and £60 in UK government bonds, raising the total stock of APF assets to £445 billion.	Bank rate reduced to 0.25% from 0.5%
8/4/2016	TFS	MP statement	TFS announced: BOE announces new long-term lending facility with £100 billion available in four-year loans to banks. TFS will include incentives for banks to increase lending activity. Banks can make drawdowns until February 28, 2018.	Bank rate reduced to 0.25% from 0.5%
8/3/2017	TFS	MP statement	MPC confirms the final day for TFS drawdowns will be February 28, 2018.	
11/2/2017	NA	MP statement	NA	MPC raises the Bank rate from 0.25% to 0.50%
6/21/2018	APF	MP statement	MPC intends not to reduce the stock of purchased assets until the bank rate reaches around 1.5%, compared with the previous guidance of around 2%. Any reductions will be at a gradual and predictable pace.	
8/2/2018	NA	MP statement	NA	MPC raises the policy rate from 0.50% to 0.75%.

Table 2D

Bank of Japan

Date	Program	Event (link)	Brief description	Interest rate news
12/2/2008	SFSOs	Unscheduled monetary policy meeting	BOJ to operate a facility through the end of April to lend an unlimited amount to banks at the uncollateralized overnight call rate and collateralized by corporate debt.	
12/19/2008	Outright JGB, corporate finance instrument (CFI) purchases	Statement on monetary policy	Outright purchases expanded: BOJ increases monthly JGB purchases (last increased October 2002) from ¥1.2 trillion to ¥1.4 trillion; will also look into purchasing commercial paper (CP).	Target for the uncollateralized overnight call rate lowered from 0.3% to 0.1%
1/22/2009	Outright CFI purchases	Statement on monetary policy	Outright purchases announced: BOJ to purchase up to ¥3 trillion in CP and asset-backed CP and is investigating outright purchases of corporate bonds.	
2/19/2009	Outright CFI purchases	Statement on monetary policy	Outright purchases expanded: BOJ to extend CP purchases and SFSOs through end of September (previously end of March) and will purchase up to ¥1 trillion in corporate bonds.	
3/18/2009	Outright JGB purchases	Statement on monetary policy	Outright purchases expanded: BOJ increases monthly JGB purchases from ¥1.4 trillion to ¥1.8 trillion.	
7/15/2009	Outright CFI purchases, SFSOs	Statement on monetary policy	Programs extended: BOJ extends SFSOs and outright purchases of CP and bonds throughout the end of the year.	
10/30/2009	Outright CFI purchases, SFSOs	Statement on monetary policy	Status of programs: Outright purchases of corporate finance instruments to expire at the end of 2009 as expected, but SFSOs will be extended through 2010; Q1: ample liquidity provision past 2010: Q1 will occur through funds-supplying operations against pooled collateral, which will accept a larger range of collateral.	
12/1/2009	Fixed-rate operations (FROs)	Statement on monetary policy	Facility announcement: BOJ to offer ¥10 trillion in three-month loans against the full menu of eligible collateral at the uncollateralized overnight call rate.	
3/17/2010	FROs	Statement on monetary policy	Facility expansion: BOJ expands the size of FROs to ¥20 trillion.	
5/21/2010	GSFF	Statement on monetary policy	GSFF announcement: BOJ to offer one-year loans to private financial institutions with project proposals for "strengthening the foundations for economic growth."	
8/30/2010	FROs	Unscheduled monetary policy meeting	Facility expansion: BOJ adds ¥10 trillion in 6-month loans to the FROs.	Uncollateralized overnight call rate targeted at around 0-0.1%. BOJ will maintain virtually zero interest rates until "price stability is in sight."
10/5/2010	Comprehensive monetary easing (CME)	Statement on monetary policy	APP established: BOJ will purchase ¥5 trillion in assets (¥3.5 trillion in JGBs and Treasury discount bills, ¥1 trillion in CP and corporate bonds, and ¥0.5 trillion in ETFs and J-REITs).	
3/14/2011	CME	Statement on monetary policy	APP expanded: BOJ to purchase an additional ¥5 trillion in assets (¥0.5 trillion in JGBs, ¥1 trillion in Treasury discount bills, ¥1.5 trillion in CP, ¥1.5 trillion in corporate bonds, ¥0.45 trillion in ETFs, and ¥0.05 trillion J-REITs).	

Table 2D, cont'd
Bank of Japan

Date	Program	Event (link)	Brief description	Interest rate news
6/14/2011	GSFF	Statement on monetary policy	GSFF expanded: BOJ makes available another ¥0.5 trillion in loans to private financial institutions for investing in equity and extending asset-based loans.	
8/4/2011	CME	Statement on monetary policy	Programs expanded: BOJ to purchase an additional ¥5 trillion in assets (¥2 trillion in JGBs, ¥1.5 trillion in Treasury discount bills, ¥0.1 trillion in CP, ¥0.9 trillion in corporate bonds, ¥0.5 trillion in ETFs, and ¥0.01 trillion J-REITs); 6-month collateralized loans through FROs are expanded by ¥5 trillion.	
10/27/2011	CME	Statement on monetary policy	APP expanded: BOJ to purchase an additional ¥5 trillion in JGBs.	
2/14/2012	CME	Statement on monetary policy	APP expanded: BOJ to purchase an additional ¥10 trillion in JGBs.	BOJ will maintain virtually zero interest rates until 1% inflation "is in sight."
3/13/2012	GSFF	Statement on monetary policy	GSFF expanded: BOJ to make available another ¥2 trillion in loans to private financial institutions, including ¥1 trillion in USD-denominated loans and ¥0.5 trillion in smaller-sized (¥1-10 million) loans.	
4/27/2012	CME	Statement on monetary policy	APP expanded/FROs reduced: BOJ to purchase an additional ¥10 trillion in JGBs, ¥0.2 trillion in ETFs and ¥0.01 in J-REITs. BOJ also reduces the availability of 6-month FRO loans by ¥5 trillion.	
7/12/2012	CME	Statement on monetary policy	APP expanded/FRO reduced: BOJ to purchase an additional ¥5 trillion in Treasury discount bills and reduces the availability of FRO loans by ¥5 trillion.	
9/19/2012	CME	Statement on monetary policy	APP expanded: BOJ to purchase an additional ¥5 trillion in JGBs and ¥5 trillion in Treasury discount bills.	
10/30/2012	CME, SBLF	Statement on monetary policy	APP expanded/SBLF announced: BOJ will purchase an additional ¥5 trillion in JGBs, ¥5 trillion in Treasury discount bills, ¥0.1 trillion in CP, ¥0.3 trillion in corporate bonds, ¥0.5 trillion in ETFs, and ¥0.01 trillion in J-REITs. Through the SBLF it will fund up to 100% of depository institutions' net increase in lending to the nonfinancial sector.	
12/20/2012	CME	Statement on monetary policy	APP expanded: BOJ will purchase an additional ¥5 trillion JGBs and ¥5 trillion in Treasury discount bills.	
1/22/2013	APP, price stability target	Monetary policy release	APP expanded: Beginning in January 2014, the BOJ will purchase about ¥10 trillion in Treasury bills and ¥2 trillion in JGBs each month. BOJ also announces inflation target of 2%.	BOJ will maintain virtually zero interest rates as long as the Bank judges it appropriate.
4/4/2013	QQE	Monetary policy release	QQE announced: BOJ to make annual purchases of ¥50 trillion in JGBs, ¥1 trillion in ETFs, and ¥30 billion in J-REITs. Purchases will extend average maturity of JGB holdings from less than 3 years to about 7 years. BOJ to make purchases to maintain holdings of ¥2.2 trillion worth of CP and ¥3.2 trillion worth of corporate bonds.	

Table 2D, cont'd
Bank of Japan

Date	Program	Event (link)	Brief description	Interest rate news
2/18/2014	SBLF, GSFF	Monetary policy release	GSFF/SBLF expanded: GSFF lending limit increased from ¥3.5 to ¥7 trillion. Under SBLF, banks can borrow up to double their net increases in lending. Both programs extended until April 30, 2015.	
10/31/2014	QQE	Monetary policy release	QQE expanded: BOJ to make annual purchases of ¥80 trillion in JGBs, ¥3 trillion in ETFs, and ¥90 billion in J-REITs. BOJ will also set a target range for the average maturity of JGB holdings of 7–10 years.	
1/21/2015	SBLF, GSFF	Monetary policy release	GSFF/SBLF expanded: GSFF lending limit increased from ¥7 trillion to ¥10 trillion. BOJ extends both lending programs by one year.	
12/18/2015	SBLF, GSFF, QQE	Monetary policy release	GSFF, SBLF extended: BOJ extends both lending programs by one year. QQE enhanced: BOJ to expand target range for the average maturity of JGB holdings to 7–12 years.	
1/29/2016	QQE with a negative interest rate	Monetary policy release	NA	BOJ to apply –0.1% interest rate on excess reserves held with the central bank.
7/29/2016	QQE, USD lending program	Monetary policy release	QQE expanded: BOJ to increase purchases of ETFs to ¥6 trillion per year. BOJ will also increase the size of its USD funds-supplying operations from \$12 billion to \$24 billion.	
9/21/2016	QQE with YCC	Monetary policy release	BOJ to institute “inflation overshooting commitment,” stating that it will pursue monetary easing until year-over-year inflation exceeds 2% and “stays above the target in a stable manner.”	BOJ to target 0% for the 10-year JGB yield and maintain a –0.1% interest rate on excess reserves.
1/31/2017	SBLF, GSFF	Monetary policy release	SBLF, GSFF extended: BOJ extends both lending programs until July 1, 2018.	
1/23/2018	SBLF, GSFF	Monetary policy release	GSFF, SBLF extended: BOJ extends both lending programs until June 30, 2019.	
7/31/2018	QQE with yield curve control	Monetary policy release	BOJ will reduce the size of the policy-rate balance (balance of reserves to which the negative policy rate applies) from around ¥10 trillion to ¥5 trillion.	BOJ will maintain “extremely low levels of short- and long-term interest rates for an extended period of time.”
1/23/2019	SBLF, GSFF	Monetary policy release	GSFF, SBLF extended: BOJ extends both lending programs by a year.	
4/25/2019	SBLF, GSFF	Monetary policy release	GSFF, SBLF extended to June 30, 2021.	BOJ will maintain the current low interest rates “at least through around spring 2020.”
12/19/2019	SBLF, ETFs	News release	BOJ introduced the ETF lending facility, through which it can lend its ETF holdings to market participants to improve market liquidity. BOJ also will allow counterparties to roll over SBLF loans under certain conditions.	

Because the international business cycle and movements in international commodity prices tend to influence major countries in a similar manner, major central banks generally face similar risks to their goals and similar pressures and so tend to move their policy rates in the same direction. For example, in 2008-09, all the major central banks tried to ease monetary and financial conditions. The 2012-15 period was different, however, in that the major central banks saw varied risks to their objectives and took divergent approaches. While the Fed worked to remove some of the unusual monetary accommodation that it had provided, the ECB was initially concerned with excessive inflation and then persistent deflation, the BOE focused on creating incentives for more efficient use of the reserves that it provided, and the BOJ moved toward much more aggressive stimulatory policies.

5.1 The BOE Funding for Lending Scheme: July 2012

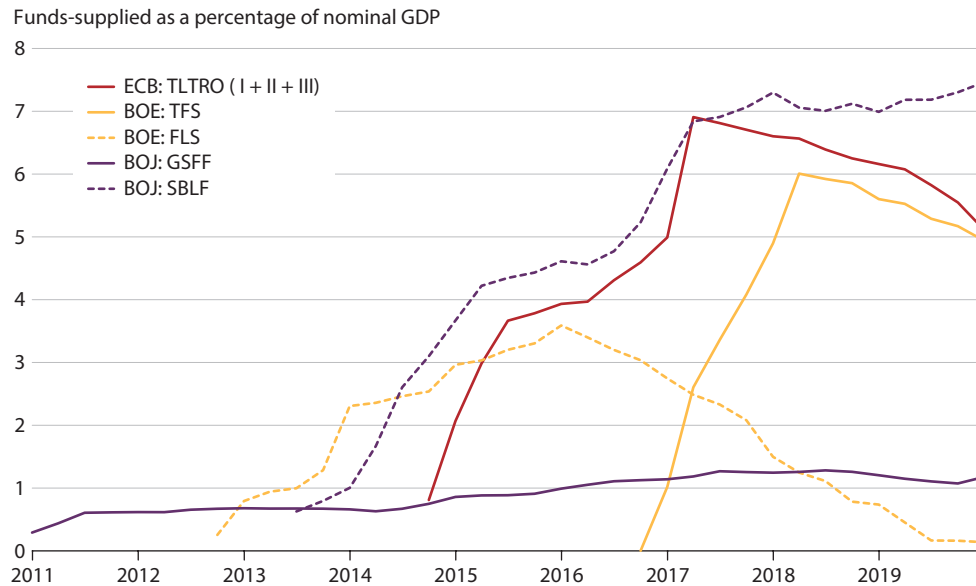
In the latter half of 2012, the BOE faced several challenges, many of which related to the euro area debt crisis of the previous year. Although the United Kingdom was not a member of the eurozone—maintaining an independent monetary policy with an independent currency, the pound—the debt crisis affected the United Kingdom through its extensive trade and financial links with the eurozone. The U.K. banking system was vulnerable. Many U.K. banks had lent to French banks, which held a lot of debt from fiscally troubled Italy and Spain. A debt default by those countries could have easily impaired the balance sheets of U.K. banks.

In 2012, the European macroeconomy had weakened. Eurozone growth had been very low from 2011:Q3 through 2012:Q2, and U.K. output growth had been only modestly better at 1.0 to 1.5 percent. U.K. inflation had been above the BOE Monetary Policy Committee's (MPC's) 2 percent target.

Despite substantial monetary easing by the BOE, credit was not flowing freely in the U.K. financial system. Hoping to remedy this, on July 13, 2012, the U.K. Treasury and BOE jointly announced the new Funding for Lending Scheme (FLS), which would lend U.K. Treasury bills to banks for use as collateral in money markets. The FLS loans would be collateralized by lower-quality assets. The asset swap allowed the BOE to accept the credit risk associated with lower-quality, heterogeneous assets. The MPC supplemented the FLS announcement with FG on August 7, 2013, when it pledged to keep rates low while unemployment remained above 7 percent (BOE, 2013).

The FLS was the first of the *conditional credit programs* that used incentives for banks to increase lending to households and businesses. These programs conditioned either borrowing quantities or borrowing prices (interest rates on borrowing) on each bank's loan growth. They often also offered cheap loans at three- to four-year terms, which are *unusually* long maturities for obligations to central banks. The use of long-maturity loans reduces rollover risk for commercial banks, as only a small portion of their funding must be rolled over in any given period. In addition, long-term funding reduces maturity transformation risk, as the yields on funding more closely match yields on loans. By making more loans, banks would take advantage of the excess reserves that QE policies had created. The BOJ and ECB would later adopt their versions of conditional credit programs, and the BOE would later introduce a second variant.

The U.K. Treasury and BOE designed the FLS to encourage broad participation and conditioned borrowing quantities on bank loans to the nonfinancial sector. A bank could initially

Figure 6**Conditional Credit Programs**

NOTE: The figure depicts outstanding loan balances as a share of nominal GDP for each conditional credit program. "ECB: TLTRO" includes outstanding loans provided through TLTRO I, TLTRO II, and TLTRO III.

SOURCE: ECB, BOE, BOJ, and Haver Analytics.

borrow U.K. Treasury bills worth up to 5 percent of its outstanding loans to U.K. businesses and households. The FLS rewarded banks for increased lending and penalized banks that cut back.¹³ Each bank's borrowing allowance would increase one-for-one with net new loans to the nonfinancial sector. Banks with declining lending would pay a higher interest rate on borrowed funds, 25 basis points higher for every 1 percent decline in lending. The BOE capped FLS interest rates at 1.5 percent.

In its first year, the FLS disbursed the modest amount of £17 billion (\$26.6 billion) in U.K. Treasury bills—less than a quarter of the facility's total lending capacity. Still, the program reduced borrowing costs. The FLS announcement prompted a number of banks to announce "reductions in the rates on certain mortgage and small-business loans," and LIBOR rates fell further in the weeks following the announcement (BOE, 2012). By directly targeting bank lending, the FLS complements QE policies that target asset prices (Churm et al., forthcoming). At its peak effects, the FLS reduced banks' funding costs; that is, unsecured bond spreads declined by 75 basis points, increased GDP by 0.8 percent, and boosted the annual inflation rate by 0.6 percentage points (Churm et al., forthcoming).

In April 2013, the BOE extended the FLS by 12 months and expanded borrowing quantities. That is, to increase incentives for small and medium-sized enterprise (SME) lending, the BOE would add £10 to banks' borrowing allowances for every £1 net increase in SME lending; the BOE decreased that ratio to £5:1 in 2014.¹⁴ In the 12 months following the April 2013

extension, the FLS more than doubled in size as banks borrowed an additional £27 billion (\$42.2 billion) in U.K. Treasury bills.

The FLS grew to a moderate size compared with other conditional credit facilities (Figure 6), peaking in size in 2015:Q4 at £70 billion (\$107 billion), equal to 3.7 percent of U.K. GDP. The BOE twice postponed the expiration of the FLS before officially ending new drawdowns on January 31, 2018.¹⁵

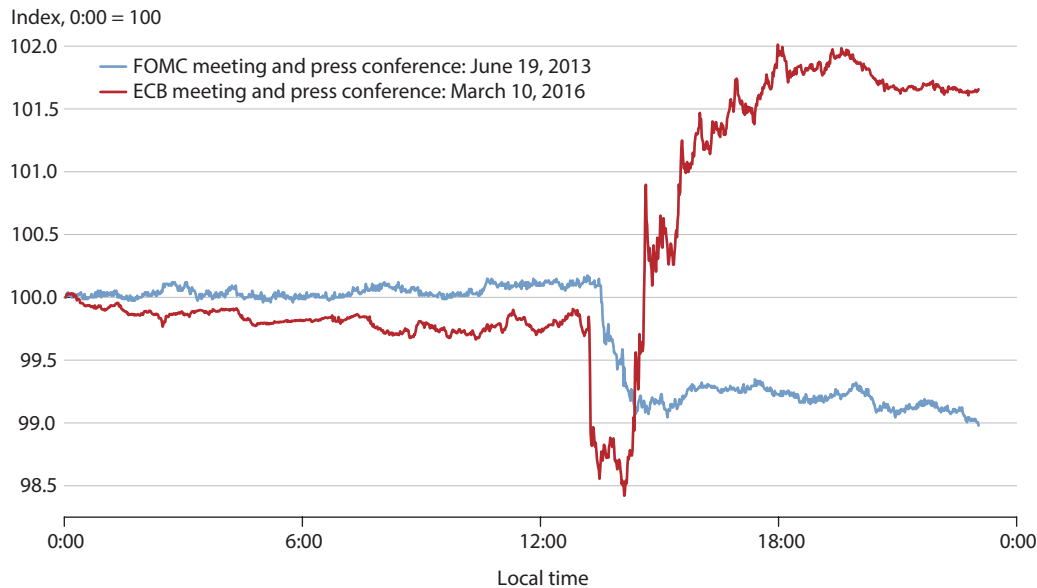
Aside from expanding the FLS, the BOE maintained steady policies from 2012 until 2016 (see Figures 3 and 4). Kristin Forbes, a member of the BOE MPC from 2014 to 2017, in a 2017 speech attributed the MPC's reluctance to make major policy changes to economic and financial shocks that increased volatility and risk, which she described as "a series of unfortunate events" (Forbes, 2017, p. 4). She specifically cited the Scottish independence referendum in 2014, deflationary declines in oil prices in 2014, Greek debt restructuring in 2015, and capital outflows from China in late 2015. Forbes described her reasoning as follows: "[W]hen the case for raising interest rates is not urgent, there is little cost to delay a decision for a few weeks until a major result is known—especially if it could provide more certainty on key economic variables" (p. 10).

5.2 The Fed's Tapering and the Taper Tantrum: June 2013-December 2013

In September 2012, in response to continued weakness in the U.S. labor market and subdued inflation, the Fed embarked on QE3, an open-ended asset purchase program that would be conditioned on incoming economic data.¹⁶ Likewise, in December 2012, the Fed announced that it would switch to funding MEP purchases by issuing reserves, rather than selling short-term assets.¹⁷ Both policies were intended to further ease monetary conditions. The FOMC supplemented these asset purchase measures with the December 12, 2012, contingent guidance that "the Committee...currently anticipates that this exceptionally low range for the federal funds rate will be appropriate at least as long as the unemployment rate remains above 6-1/2 percent, inflation between one and two years ahead is projected to be no more than a half percentage point above the Committee's 2 percent longer-run goal, and longer-term inflation expectations continue to be well anchored."¹⁸

QE3 marked a major turning point for international UMPs in that it was the first major open-ended asset purchase program. Prior to QE3, programs committed to making purchases indefinitely but on a regular basis accounted for roughly 23 percent of Fed, ECB, BOE, and BOJ asset purchases. But, from the beginning of QE3 purchases in October 2012 until December 2019, open-ended strategies accounted for more than 95 percent of all asset purchases by the four major monetary authorities.

Together with other factors, QE3 and the MEP improved the U.S. economic picture. A series of positive economic reports and nonfarm payroll gains in the winter and spring of 2013 caused the FOMC to consider withdrawing some of the unusual monetary ease by scaling back QE3. On June 19, 2013, Chairman Bernanke stated "the Committee [FOMC] currently anticipates that it would be appropriate to moderate the monthly pace of purchases later this year"—conditional on a continuation of strong economic data (Fed, 2013, p. 5). Markets interpreted this remark to indicate that the Fed would soon begin reducing, that is, "tapering," QE3.

Figure 7**EUR/USD Exchange Rate on Key Monetary Policy Announcement Days**

NOTE: The blue line reflects the EUR depreciation (USD appreciation) following Chairman Bernanke's remarks on June 19, 2013, that "the Committee [FOMC] currently anticipates that it would be appropriate to moderate the monthly pace of purchases later this year" (Fed, 2013). The red line reflects the gyratory response of the EUR/USD exchange rate to the ECB statement on March 10, 2016, of additional easing and President Draghi's subsequent remarks that the ECB would likely not ease further. See the 3/10/2016 ECB press release in Table 2B. Chairman Bernanke gave his remarks in Washington, DC; President Draghi gave his remarks in Frankfurt, Germany.

SOURCE: Tickwrite and the authors' calculations.

The anticipation of tighter-than-expected monetary policy roiled financial markets, boosting long Treasury yields and the foreign exchange value of the dollar (Figure 7).¹⁹ These sharp co-movements in asset prices, which became known as the "Taper Tantrum," illustrated the powerful effect of central bank communication on financial markets (Neely, 2014). The FOMC ultimately chose not to reduce the unusual monetary ease in the summer or autumn of 2013, but the episode did shape anticipation of such actions.

On December 18, 2013, with PCE inflation hovering near 1.5 percent, below the 2 percent target, and U.S. jobs multiplying briskly, the FOMC announced that it would begin tapering QE3 asset purchases. Starting in January 2014, the Fed would reduce its monthly Treasury and MBS purchases by \$5 billion each, to \$40 and \$35 billion, respectively. Chairman Bernanke emphasized that all future reductions would be gradual and contingent on incoming economic data, and the meeting statement reassured markets that the FOMC expected low rates to persist "well past the time that the unemployment rate declines below 6.5 percent."²⁰ Stock markets rallied in response, with the S&P 500 gaining about 1.5-2 percent on the signal from the Fed that the economy was on track for recovery. The FOMC continued to taper by reducing its Treasury and MBS purchases by \$5 billion each at each of its next seven meetings.

QE3 officially ended on October 29, 2014, but the Fed continued reinvesting principal and coupon payments from maturing securities to maintain its \$4.5 trillion balance sheet. The Fed bought roughly \$1.6 trillion in Treasury securities and MBS over the course of QE3 (see Figure 5), increasing the U.S. monetary base by about 50 percent.

5.3 The BOJ Hits the Accelerator: 2013-14

The BOJ's lender-of-last resort and banking support actions during and immediately after the Financial Crisis of 2007-09 did not much change the Japanese monetary base. That is, while it pursued other supportive measures, the BOJ engaged in no significant QE in 2008-12. Panel A of Figure 4 shows this distinguished it from the other major central banks. Perhaps as a result, Japan experienced consistent deflation and very slow growth during 2008-12. This outcome motivated changes in 2013. While the Fed was considering removing some of the extraordinary accommodation that it had provided in the spring and summer of 2013, the BOJ was moving in exactly the opposite direction, to stimulate the economy in earnest.

Following his landslide victory in December 2012, newly elected Japanese Prime Minister Shinzo Abe pressured the BOJ to ramp up stimulatory measures after two decades of sluggish economic activity including several years of deflation (Figure 8), stating that “daring monetary policy” would be essential to curbing deflation (Riley, 2013).²¹ On January 22, 2013, as part of a joint statement with the Japanese government, BOJ Governor Masaaki Shirakawa stated that the BOJ would introduce open-ended asset purchases (BOJ, 2013a, see Appendix A). Specifically, the Japanese authority would purchase ¥13 trillion (\$163 billion) in short- and long-dated JGB each month, starting in January 2014 at the conclusion of the then-ongoing asset purchases of ¥36 trillion over the course of 2013 (BOJ, 2013b). The BOJ also doubled its inflation target from 1 percent to 2 percent to bolster inflation expectations. Many observers viewed the joint announcement as a watershed linking the efforts of the central bank and national government (Irwin, 2013). The large asset purchase policy constituted both expansive easing and another step by major central bankers toward open-ended QE, but the delayed implementation indicated a lack of urgency that confounded market participants (Kihara and Kajimoto, 2013).²²

To achieve its ever-elusive inflation goal, the BOJ also planned to provide accommodation through two programs collectively dubbed the Loan Support Program (LSP): (i) the GSFF, which had been introduced in 2010 and grew to ¥3.4 trillion (\$34.8 billion) in 2013:Q1, and (ii) the Stimulating Bank Lending Facility (SBLF), which had been announced in October 2012 and began allocating funds in 2013:Q2.

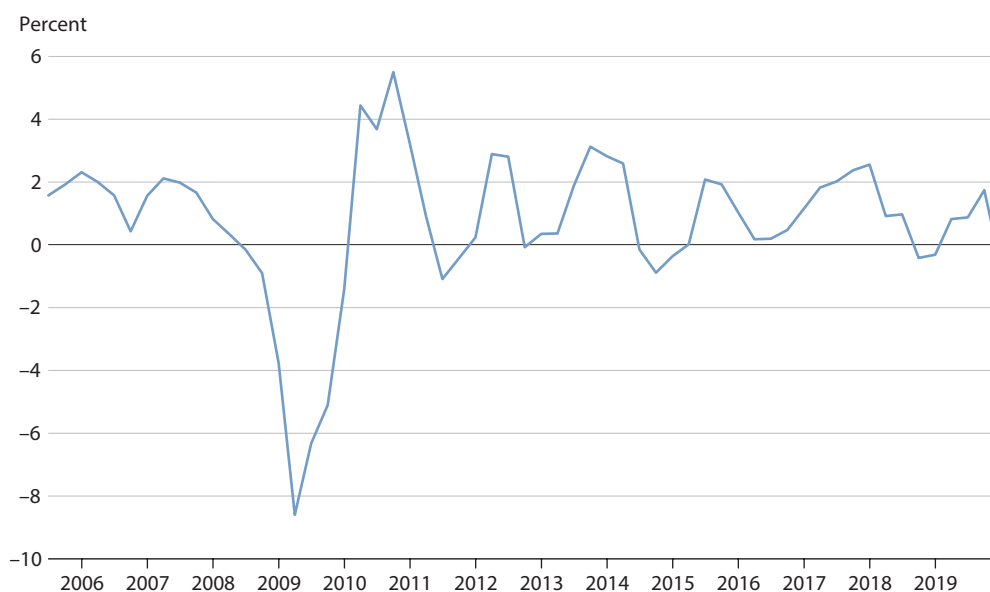
Like the BOE's FLS, the SBLF conditioned a bank's access to cheap credit on its loan growth, although, unlike the FLS, the SBLF lent money, not bonds, and did not penalize banks for scaling back loans. Through the SBLF, the BOJ pledged to fund up to 100 percent of banks' increases in net lending relative to 2012:Q4. These loans carried maturities of one to three years, though they could be rolled over for a fourth year, at the uncollateralized overnight call rate, which was only 0.1 percent in June 2013.

Despite these nascent stimulatory measures, Japanese inflation slipped further into negative territory during the spring of 2013, increasing pressure on the BOJ to act (see Panel B of

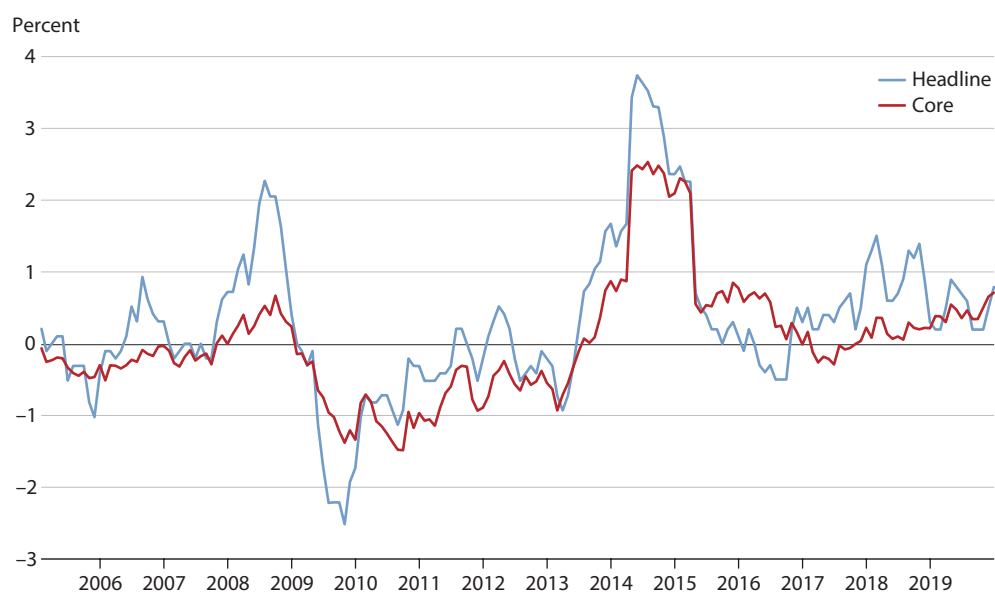
Figure 8

Japanese Economic Performance, 2005-19

A. Year-over-year Japanese real GDP growth



B. Year-over-year Japanese inflation



SOURCE: Haver Analytics and the Organisation for Economic Co-operation and Development.

Figure 8). On April 4, 2013, the BOJ took dramatic action when newly appointed Governor Haruhiko Kuroda announced the BOJ's decision to officially change its main policy instrument again, from the uncollateralized overnight call rate to "QQ targeting." That is, the BOJ began "quantitative and qualitative easing" (QQE), which involved both the traditional UMP strategy of increasing the maturity of asset holdings and the evolution toward state-contingent, open-ended programs, an approach that the Fed first turned to in September 2012. The BOJ again supplemented the QQE announcement with a promise that it would continue QQE until inflation stably reached 2 percent.

Adopting the QQE strategy made the BOJ the second major central bank, after the Fed, to eschew lump-sum asset purchases in favor of continuous and contingent purchases. Such a strategy is consistent with the advice in Bullard (2010) and Waller and Ricketts (2014), who argue for flexible policy frameworks to respond to incoming information, as in conventional interest rate policy.

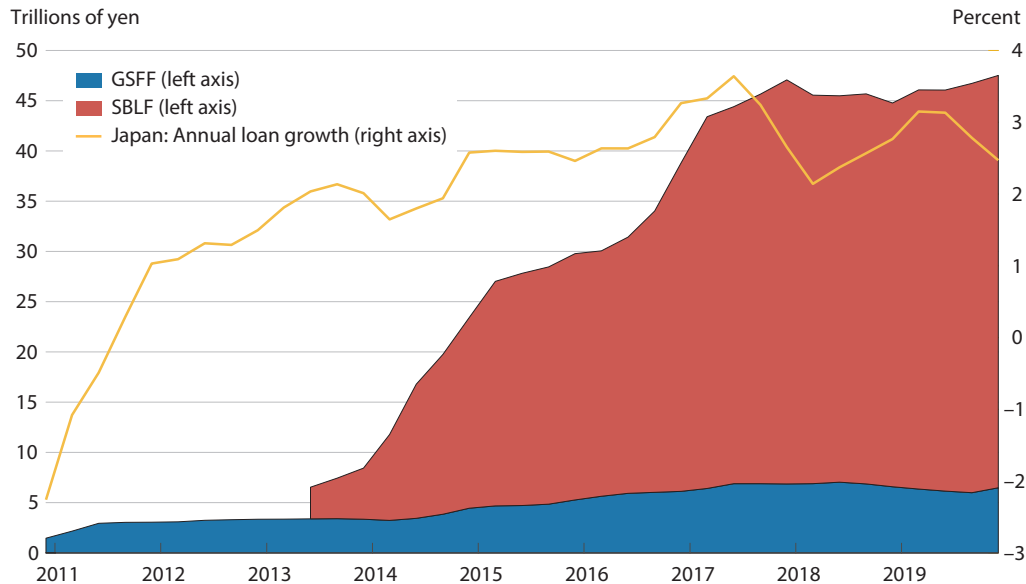
The QQE strategy committed the BOJ to purchase assets at a pace of ¥50 to 55 trillion (\$512 to \$563 billion) per year, consisting of ¥50 trillion (\$512 billion) in JGBs, ¥1 trillion (\$10 billion) in exchange-traded funds (ETFs), and ¥30 billion (\$307 million) in Japanese real estate investment trusts (J-REITs). These purchases focused on longer-dated JGBs to raise the average maturity of the BOJ's JGBs holdings from 3 years to 7 years. The QQE policy also called for very modest purchases of private assets to maintain holdings of ¥2.2 trillion (\$22.5 billion) in commercial paper and ¥3.2 trillion (\$32.8 billion) in corporate bonds.²³

The scale of the April 2013 QQE announcement exceeded expectations: Anticipated QQE purchases would outstrip the Fed's QE3 in size relative to GDP—they boosted the BOJ balance sheet by about 0.9 percent of GDP per month, while the Fed's QE3 boosted the Fed balance sheet by only 0.5 percent of U.S. GDP per month.²⁴ QQE also targeted both public and private assets. These asset purchases, along with the LSP, would double Japan's monetary base within two years, and the BOJ hoped that it would achieve its 2 percent inflation target within that time horizon. Markets rallied on the news of greater-than-expected monetary easing, driving the Nikkei 225—the primary Japanese stock index—up 2.2 percent by the end of the day, while the 10-year yield plunged almost 20 basis points to match a record low (McLannahan and Soble, 2013).

5.4 The BOJ Extends and Expands Lending and QQE: 2014-15.

The adoption of QQE in April 2013 was only the beginning of BOJ expansionary monetary policy measures. At its February 2014 policy meeting, the Policy Board of the BOJ announced a series of enhancements to the LSP, including one-year extensions to the GSFF and the SBLF. The BOJ also doubled the GSFF's and SBLF's lending capacity and increased the maturity limit of GSFF loans from three years to four years. These modifications rapidly expanded SBLF drawdowns (Figure 9), but some market participants doubted that these changes would significantly affect demand for credit (McLannahan, 2014).

Figure 6 illustrates that, relative to nominal GDP, the SBLF has been the largest conditional lending program among those administered by the four major central banks. As of December 2019, the GSFF and SBLF had lent out a combined ¥48 trillion (\$440 billion),

Figure 9**Bank of Japan Loan Support Program, Amounts Outstanding**

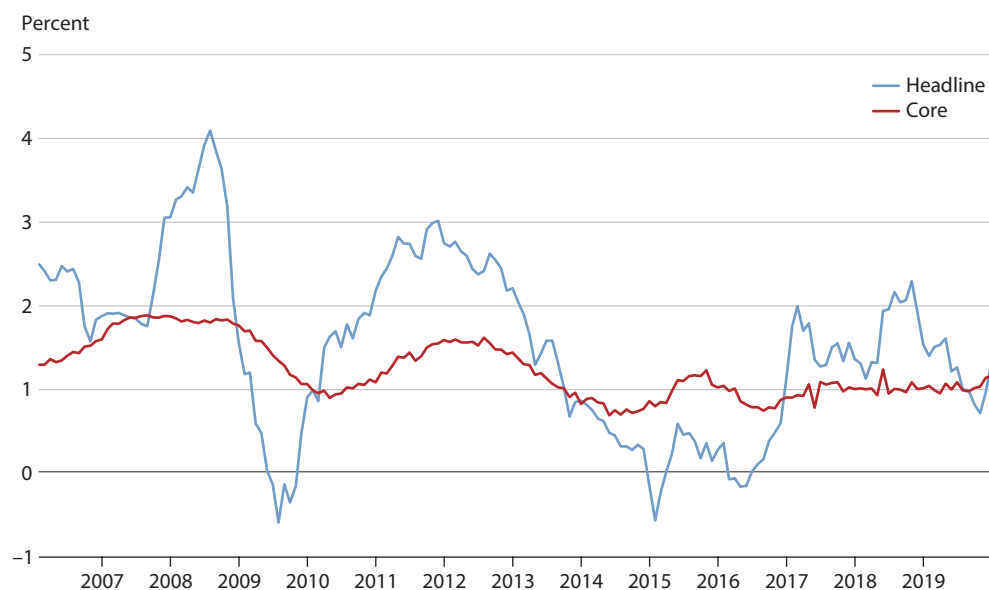
NOTE: Annual loan growth is measured as the year-over-year change in the amount of outstanding loans by Japanese banks to the nonfinancial sector.

SOURCE: BOJ.

equivalent to about 8.6 percent of Japanese GDP. As of January 2021, the GSFF and SBLF loan disbursements are set to finish in June 2022. The BOJ's reliance on the GSFF and the SBLF reflect the essential role that banks play in Japan and the importance of long-term lending as a means of unconventional monetary easing for the central bank.

A series of shocks in 2014 produced further deflationary pressures in Japan. Specifically, rapidly declining oil prices restrained global inflation, including inflation in Japan and the euro area (see Panel B of Figure 8 and of Figure 10). In Japan itself, a tax hike that raised the price level on a one-time basis also slowed household spending, which fed deflation concerns. To preempt these downside risks to price stability, the Japanese monetary authority expanded QQE on October 31, 2014, raising its annual asset purchases from ¥50 trillion to ¥80 trillion (\$473 billion to \$757 billion) in JGBs, from ¥1 trillion to ¥3 trillion (\$9.5 billion to \$28.4 billion) in ETFs, and from ¥30 billion to ¥90 billion (\$284 million to \$852 million) in J-REITs, which was a 63 percent increase in the pace of asset purchases. The BOJ further extended the average remaining maturity of its JGB portfolio from seven years to a target range of seven to 10 years.²⁵ This monetary expansion reduced both Japanese yields and the foreign exchange value of the yen. The BOJ Policy Board approved the measures in an unusually tight 5-4 vote, demonstrating serious division over the measures (Kihara and Kajimoto, 2014).

Downward price pressures continued. On January 21, 2015, the BOJ downgraded its year-ahead inflation forecast to 1 percent. To help achieve its 2 percent inflation target, the

Figure 10**Year-Over-Year Euro Area Inflation**

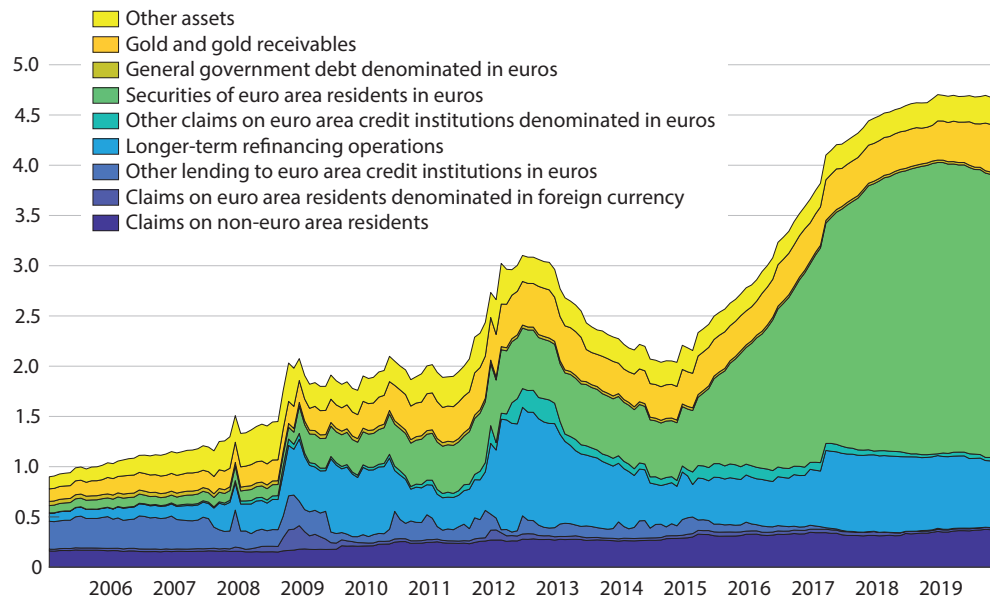
SOURCE: ECB and Haver Analytics.

BOJ extended its LSP for another year and raised the GSFF's total funding cap from ¥7 trillion to ¥10 trillion (\$57.9 billion to \$82.6 billion).²⁶ A year later, at its December 2015 meeting, the BOJ approved an increase in the target range for the average maturity of its JGB holdings and extended the LSP for another year.

5.5 Deflation Fears in the Euro Area: 2012-14

While the Fed was receiving positive macroeconomic news in early- to mid-2013, the ECB—like the BOJ—faced tepid growth and deflation fears. Despite a global recovery, euro area growth in 2012-13 was sluggish, below 2 percent on an annual basis in every quarter. At the same time, euro area headline inflation receded well below the levels of 2011-12, when it exceeded the ECB's goal, which was to keep inflation close to but below 2 percent. Figure 10 shows that euro area headline inflation declined from 2.5 percent in 2012 to 1.4 percent in 2013, as energy and food inflation eased.²⁷ By the end of 2013, euro area inflation fell to only 0.9 percent, while unemployment remained high, near 12 percent.²⁸ The lackluster euro area growth in 2012-13, along with weak commodity and energy prices, stoked fears of deflation (Kang, Ligthart and Mody, 2015). ECB communications frequently referenced concerns about expected inflation, including market-based measures, such as those from yield spreads.²⁹

The ECB Governing Council lowered policy rates in May 2013 and again in November 2013, reducing the main refinancing operations (MRO) rate to just 0.25 percent, although it judged policy to be already accommodative. The Governing Council also employed expansionary FG in July 2013, stating that it expected key ECB interest rates to remain at or below then-

Figure 11**ECB Assets (Trillions of EUR)**

NOTE: "Securities of euro area residents in euros" includes bonds acquired under the ECB's APP. The figure shows a sustained increase in this category following the adoption of open-ended QE in January 2015. Holdings from all TLTRO are included in the LTRO. Main refinancing operations are included in "Other lending to euro area credit institutions in euros."

SOURCE: ECB and Haver Analytics.

current levels for an extended period. The Governing Council confirmed this statement in August 2013 and reiterated it in January 2014. Despite these measures, the monetary base—and particularly longer-term refinancing operations (LTRO)—shrank as banks repaid loans early. Figure 11 illustrates the declines in these quantities from 2012 through most of 2014.

5.6 The ECB Goes Negative: June 2014

Headline inflation in the euro area dipped still lower and undershot expectations, registering at only 0.5 percent in the 12 months to May 2014 (see Figure 10). On June 5, 2014, ECB President Mario Draghi announced two stimulatory measures: negative deposit rates and a conditional credit program known as Targeted LTRO (TLTRO). President Draghi also hinted at further asset purchases. The ECB applied its new deposit rate of -0.1 percent only to banks' excess reserves; it applied the higher MRO rate to required reserves. Because retail bank depositors strongly resist negative interest rates for their deposits, negative interest rates may tend to favor banks with market funding over those with deposit funding (Bernanke, 2016, and Schepens, 2018).³⁰ This move to negative interest rates made the ECB the first of the four major central banks to set a negative deposit rate.³¹ The ECB aimed to encourage banks to make additional loans rather than hold excess reserves with the central bank.³²

Table 3**Conditional Credit Programs**

Central bank	Title	Peak size (millions, local currency)	Peak size (millions of USD)	Borrowing allowance linked to net lending?	Increase to borrowing allowance for each increase in net lending of 1 unit of local currency	Interest rate linked to net lending?
BOE	FLS	£69,500	\$105,500	Yes	£1*	Yes
BOE	TFS	£127,000	\$176,800	Yes	£1	Yes
BOJ	GSFF	¥7,034,800	\$64,500	No	NA	No
BOJ	SBLF	¥41,036,900	\$377,500	Yes	¥2, starting February 2014 (previously ¥1)	No
ECB	TLTRO I	€425,300	\$470,500	Yes	€3	No
ECB	TLTRO II	€740,200	\$912,700	No	NA	Yes
ECB	TLTRO III	€101,100	\$112,500	No	NA	Yes

NOTE: *Under the FLS, a £1 increase in net lending to SMEs between April and December 2013 (January 2014 and December 2015) raised a bank's borrowing allowance by £10 (£5).

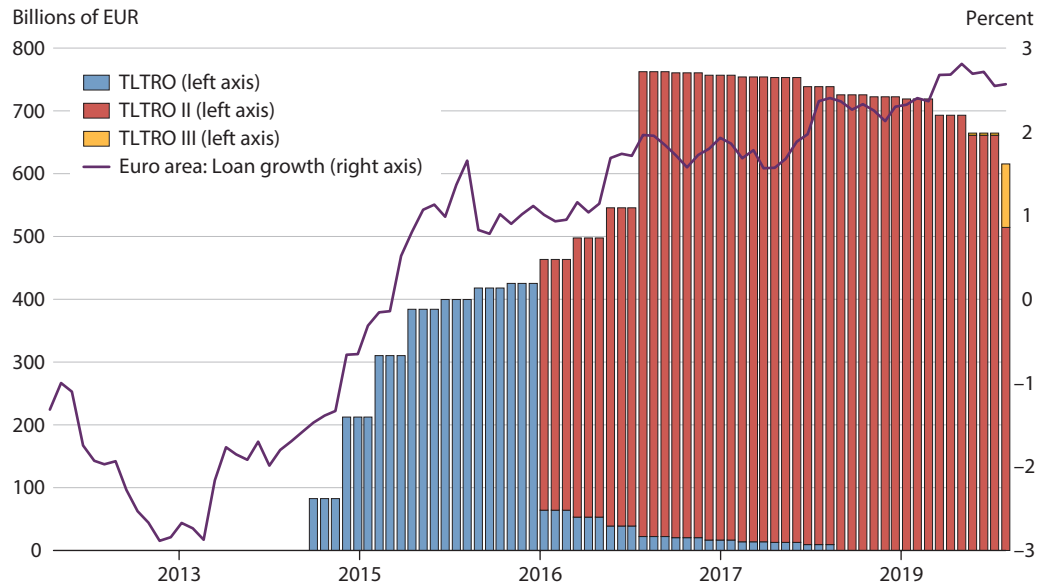
SOURCE: Haver Analytics, Organisation for Economic Co-operation and Development, Fed, BOE, BOJ, and ECB.

The ECB complemented its negative interest rate policy by introducing TLTRO at its June 5, 2014, meeting, hoping to boost lending to the real economy because lending had been shrinking in 2013 (Figure 12) (Praet, 2014). TLTRO's features resembled those of the BOE's FLS and the BOJ's SBLF, including provisions for four-year loans to banks and low interest payments, only 10 basis points above the MRO rate. The TLTRO program followed the SBLF in conditioning banks' borrowing allowances, but not borrowing rates, on increases in net loans, excluding mortgages, to the nonfinancial sector (Table 3).

The ECB provided €80 billion (\$89 billion) in loans during its first TLTRO allotment on September 18, 2014, and had disbursed loans worth €425 billion (\$472 billion) by its final major allotment on March 24, 2016 (see Figure 12). As of March 2016, of the three major conditional credit programs—TLTRO, SBLF, and FLS—the TLTRO program was the largest in absolute terms, but the SBLF remained the largest relative to GDP (see Figure 6). The TLTRO was about 4.0 percent as large as the euro area's GDP, while the SBLF was about 4.6 percent as large as Japan's GDP.

The ECB's use of TLTRO reflected central bankers' growing emphasis on ensuring that credit expansions would fund real activity and signaled central bankers' acceptance of conditional credit programs as important tools. By 2014:Q4, the BOE, BOJ, and ECB all operated conditional credit programs, with a combined total of about \$555 billion of outstanding loans to banks.

In addition to announcing TLTRO and negative interest rates on June 5, 2014, President Draghi foreshadowed additional asset purchases, stating that the ECB would "intensify preparatory work" related to purchases of ABS (ECB, 2014b). The ECB's unexpected stimu-

Figure 12**TLTRO, Outstanding Balances**

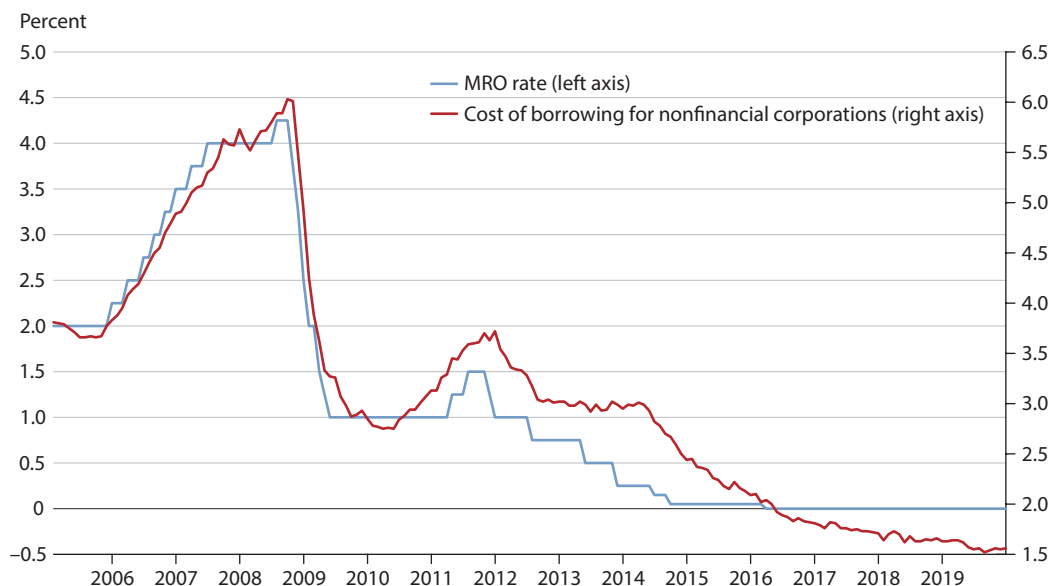
NOTE: "Euro area: Loan growth" is measured as the year-over-year change in the amount of outstanding loans by euro area banks to the nonfinancial sector.

SOURCE: ECB and Haver Analytics.

lus prompted an equity rally; the Euro Stoxx 50 Index rose to a six-year high on June 5, 2014. According to Trevor Greetham, a director at Fidelity Worldwide Investment, "Draghi handsomely beat expectations by adopting all of the measures under discussion and leaving the door open to future QE" (Monaghan and Inman, 2014). Following the June 2014 announcement, Figure 13 shows that borrowing costs for nonfinancial corporations declined persistently for the first time in over a year. In addition, the ECB (2015) argues that the TLTRO appear to have particularly reduced rates in financially vulnerable countries.

5.7 The ECB's Covered Bond and Asset-Backed Securities Purchase Programmes

Following the ECB's June 5, 2014, announcement of negative interest rates and TLTRO, euro area inflation continued to be undesirably low. The core harmonized CPI (HCPI)—all items less food, energy, tobacco, and alcohol—had grown only 0.7 percent over the 12 months to May, while lending to euro area businesses reached a seven-year low. At the Fed's Jackson Hole Conference in August 2014, President Draghi reassured a concerned audience that the ECB "will use all the available instruments needed to ensure price stability in the medium-term" (Jones, 2014). On September 4, 2014, the ECB Governing Council lowered its MRO rate to nearly zero (0.05 percent), its deposit rate further into negative territory (−0.2 percent), and announced two new asset purchase programs: an ABS Purchase Programme (ABSP)³³ and a third CBPP (CBPP3).

Figure 13**Euro Area Borrowing Costs**

NOTE: : "Cost of borrowing for nonfinancial corporations" is calculated as the weighted average of interest rates on new loans made by euro area banks to nonfinancial corporations.

SOURCE: ECB and Haver Analytics.

The ABSPP and CBPP3 aimed to facilitate “new credit flows to the economy” by lowering borrowing costs in targeted asset markets (ECB, 2014c). Both programs would begin in 2014:Q4, run for at least two years, and purchase assets with at least a BBB- credit rating. Notably, the ECB initially declined to set either a lump-sum target (like QE2) or a pace of continuing monthly asset purchases (like QE3). Two months after the initial announcement, on November 6, 2014, Draghi clarified that the new asset purchase programs and TLTRO would increase the ECB’s assets by roughly €750 billion to €1 trillion (\$1 trillion to \$1.33 trillion) by June 2016, restoring the monetary base to its early-2012 size.

Despite the fact that money creation would fund these asset purchases, President Draghi described the CBPP3 and ABSPP as credit easing, rather than QE, because these programs specifically supported covered bond and ABS markets rather than providing broad monetary stimulus.³⁴ Markets welcomed the additional monetary easing, but some analysts doubted that the relatively narrow asset purchases would be sufficient to combat deflationary pressures (Kang, Ligthart, and Mody, 2015, and Ewing and Irwin, 2014).

5.8 The ECB Expands the APP: January 2015

Despite the negative interest rates and asset purchase programs announced at the June 2014 meeting, the ECB remained concerned about undesirably low inflation at the beginning of 2015. President Draghi stated on January 2, 2015, that “the risk that we [the ECB] do not

fulfill our mandate of price stability is higher” and that the ECB stood ready to deliver additional monetary easing (Rankin, 2015). Five days later, an official data release from the European Commission showed that the 12-month headline inflation rate dropped to –0.2 percent, rekindling deflation fears (Petroff, 2015). On January 22, 2015, the ECB responded by expanding its asset purchase program (APP) to include a Public Sector Purchase Program (PSPP) to buy medium- and long-term bonds issued by euro area governments and agencies and European institutions. The ECB would purchase €60 billion (\$67 billion) per month under the APP—the PSPP, CBPP3, and ABSPP—and such transactions would continue at least through September 2016 and would persist until the euro area experienced a “sustained adjustment” in inflation and real activity.³⁵ Markets welcomed the expanded stimulus. The Euro Stoxx 50 Index had jumped 1.6 percent, while some euro area yields declined to new lows (Jolly and Ewing, 2015).³⁶

Figures 4 and 11 show that the ECB purchase programs expanded the ECB’s balance sheet from 22 to 26 percent of euro area GDP, or slightly more than €570 billion (\$627 billion) over 2015. This aggressive, state-contingent, open-ended monetary policy mirrored the BOJ’s ongoing QQE and the Fed’s QE3, which had concluded in October 2014. While the relative size of the ECB’s expanded APP did not match that of the BOJ’s, it marked a radical step for the ECB, a relative latecomer to QE through asset purchases.

6 NORMALIZATION AND THE BREXIT VOTE: 2015-19

6.1 *The Fed Begins to Normalize: 2015-19*

In 2014 and 2015, U.S. employment continued to grow and inflation remained at acceptable levels. Under these conditions, the FOMC began considering ways to reduce the extraordinary accommodation that it had provided and normalize U.S. monetary conditions. There would be two components to this normalization: a return to the use of short-term interest rates—the federal funds rate—as a policy tool and the gradual reduction of the huge quantity of assets held on the balance sheet.

The FOMC reassured markets that monetary policy would not tighten suddenly, carefully avoiding spooking financial markets, as it had inadvertently done during the Taper Tantrum. On March 19, 2014, the FOMC stated that it expected low rates “for a considerable time after the asset purchase program ends.” On December 17, 2014, the committee said that it “judges that it can be patient in beginning to normalize the stance of monetary policy.” Still, as the economy improved, normalization looked more likely.

On December 16, 2015, with U.S. unemployment having fallen to 5 percent, the FOMC raised the target range for the federal funds rate by $\frac{1}{4}$ percentage point to the 25- to 50-basis-point range.³⁷ In the following years, the FOMC followed this action with eight more quarter point increases that brought the upper limit of the federal funds target range to 2.5 percent by December 2018.³⁸ As it removed accommodation, on June 13, 2018, the FOMC changed its FG to remove expectations that the federal fund rate would remain below its long-run rate, and then, on September 26, 2018, dropped the claim that policy would remain accommodative, which had been in place since December 2015.

On June 14, 2017, nearly three years after QE3's conclusion, the Fed released a plan to reduce its asset holdings and unwind its \$4.5 trillion balance sheet. Starting in October 2017, the Fed would allow a maximum of \$6 billion in Treasuries, and \$4 billion in agency debt plus MBS to roll off its balance sheet each month. That is, the Fed retired coupon and principal payments, rather than reinvesting them, thereby reducing the monetary base. During the first year of the normalization strategy, the Fed would increase those roll-off caps each quarter by \$6 billion and \$4 billion, respectively.

This gradual schedule provided time for markets to adjust to changes in excess reserves. Notably, Chair Yellen did not specify an ultimate goal for the size of the balance sheet, only stating that the Fed's asset holdings would be "appreciably below that seen in recent years but larger than before the financial crisis" (Fed, 2017). In contrast to the Taper Tantrum, the Fed's balance sheet normalization announcement did not seriously influence asset prices, probably because the unwinding was long expected and the Fed provided a detailed schedule for the process (Appelbaum, 2017, and Timiraos, 2017).

By 2019, however, the FOMC moved away from the idea of a relatively small balance sheet and had decided to maintain a system of "ample reserves," using the interest rate paid on reserves to influence other short-term interest rates (Fed, 2019).

6.2 The BOJ Goes Negative: January 2016

On January 29, 2016, the BOJ continued the easing actions that it had been pursuing since 2013. The Japanese monetary authority followed the Danish National Bank (DNB), the ECB and the Swiss National Bank (SNB) in announcing a negative deposit rates (–10 basis points for the BOJ) on certain reserves held with the central bank. The BOJ Policy Board described the action as a response to global economic risks, including declining oil prices, slowing Chinese growth, and global financial instability (BOJ, 2016a).

The BOJ's system of deposit rates differed slightly from the existing negative interest rate policies of the ECB and the SNB.³⁹ The BOJ adopted a layered deposit rate structure to protect banks' profitability because it feared that banks would not be able to easily pass on negative rates to depositors. The BOJ adopted "a three-tier system...in order to make sure that financial institutions' functions as financial intermediaries would not be impaired due to undue decreases in financial institutions' earnings" (BOJ, 2016b).⁴⁰ Notably, the BOJ stated that it would lower interest rates even further if economic conditions worsened.

The surprise with which markets greeted the BOJ's negative interest rate announcement highlighted a major difference between the communication strategies of the Fed and the BOJ. Except for the first QE1 announcements, which surprised markets, the Fed has generally tried hard to be transparent and to avoid startling financial markets.⁴¹ Of course, the Taper Tantrum episode of June 2013 illustrated the practical difficulties in communicating with markets. In contrast to the Fed's efforts, market observers thought that the BOJ and President Kuroda often seemed to go out of their way to surprise markets. For example, just three days prior to the negative interest rate announcement, the *Financial Times* reported, "Mr. Kuroda likes to surprise markets, but he has been emphatic in ruling out negative interest rates" (Harding, 2016).

6.3 The ECB Doubles Down in March 2016

Despite a year of uninterrupted asset purchases in 2015 and a modest drop in borrowing costs, euro area inflation remained subdued (see Figure 10) and banks' nonfinancial loan volumes grew only marginally throughout 2015 (Figure 12). With these conditions in mind, in December 2015, the ECB extended the APP until at least March 2017 and expanded the PSPP to buy regional and local euro area government debt. The ECB also began reinvesting payments from maturing securities to sustain its balance sheet.⁴²

Deflation continued to concern ECB policymakers, however. On February 29, 2016, preliminary estimates of euro area inflation dipped unexpectedly (Jones and McGee, 2016). The ECB Governing Council responded at its March 10, 2016, meeting by (i) cutting its deposit rate deeper into negative territory, (ii) implementing a new series of TLTRO, that is, TLTRO II, and (iii) expanding its APP.⁴³

Like its predecessor, the TLTRO-II program offered four-year loans to banks at minimal cost. The interest rate on TLTRO-II drawings started at the MRO rate (0 percent) and could be reduced to as low as the deposit rate (−0.4 percent) if a bank expanded its lending by 2.5 percent or more. Such incentives were designed to stimulate new credit flows to the nonfinancial sector.

While the TLTRO-II program is superficially very similar to earlier conditional credit programs, that is, TLTRO I, the BOJ's SBLF, and the BOE's FLS, its incentives differed in important ways (see Table 3). Specifically, the TLTRO II's price incentives contrast with the BOJ's SBLF and first TLTRO program, both of which offered borrowing quantity incentives instead. Although the ECB's new long-term lending program and the BOE's FLS both used interest rate incentives, the TLTRO-II program differed from the FLS in three ways. First, unlike the FLS, TLTRO II contained no provision for raising banks' borrowing allowances. Second, the FLS's incentives raised interest payments for banks that reduced lending, but the TLTRO-II program rewarded banks (i.e., charged a lower rate) for boosting loan volumes. Third, the TLTRO-II program offered euro area banks the chance to borrow for longer terms at negative interest rates, which is a powerful incentive. While the BOJ did lower its benchmark interest rate into negative territory, it did not offer negative rates in its LSP until 2020 (Haas, Neely, and Emmons, 2020).⁴⁴

The March 10, 2016, ECB press conference that announced deeper negative rates, the TLTRO II, and expanded asset purchases also illustrated the difficulty of communicating clearly without roiling markets. Although the expansionary announcements and an "easing bias" in the introductory statement initially boosted European equities, President Draghi concurrently cautioned that "[W]e don't anticipate that it will be necessary to reduce rates further."⁴⁵ This statement whipsawed stock indices. The euro first depreciated sharply by about 1.2 percent on the news of additional stimulus, then jumped skyward on President Draghi's press conference comments, gaining back about 3 percent of its value by the end of trading. For comparison, the Taper Tantrum on June 19, 2013, which is often viewed as an example of the power of central bank (mis)communication, engendered an approximately 1.0 to 1.5 percent appreciation in the foreign exchange value of the dollar (see Figure 7).

In addition to announcing negative rates and the TLTRO II in March 2016, the ECB also expanded its APP by establishing the Corporate Sector Purchase Programme (CSPP) to specifically lower funding costs for euro area businesses. The CSPP purchased investment-grade corporate bonds (BBB- or higher) with 6 months to 30 years of remaining maturity that had been issued by nonfinancial corporations within the euro area (ECB, 2016). The enhanced APP acquired €80 billion (\$88.6 billion) of bonds per month—a 33 percent increase from the previous monthly pace of €60 billion (\$66.4 billion). The ECB maintained this rate until March 2017, at which point its APP returned to its previous pace of €60 billion per month. Most of the APP expansion came from an uptick in sovereign bond purchases, while corporate bond purchases averaged €7.5 billion (\$8.3 billion) per month from June 2016 until March 2017. Nonetheless, the CSPP had acquired over 11 percent of the “CSPP-eligible bond universe” as of June 7, 2017 (ECB, 2017b, p. 40).

6.4 The BOJ Responds to the Brexit Vote: June 2016

On Thursday June 23, 2016, the citizens of the United Kingdom voted to leave the European Union. This decision, commonly called Brexit, produced widespread uncertainty, financial market volatility, and a flight to safe assets. As the yen is considered to be a very safe asset, the uncertainty associated with the Brexit vote caused it to appreciate substantially, which made Japanese exports relatively more expensive. The BOJ announced on July 29, 2016, that it planned to double its pace of ETF purchases and the size of its U.S. dollar (USD) lending operations to enhance business confidence and ensure access to funding in foreign currencies.⁴⁶ The BOJ lends in USD to support the overseas operations of Japanese firms through Japanese financial institutions. The BOJ’s policy actions failed to match market expectations of stronger stimulus (CNBC staff, 2016).

6.5 The BOE Responds to the Brexit Vote: August 2016

Journalist: “What was your biggest problem as Prime Minister?”

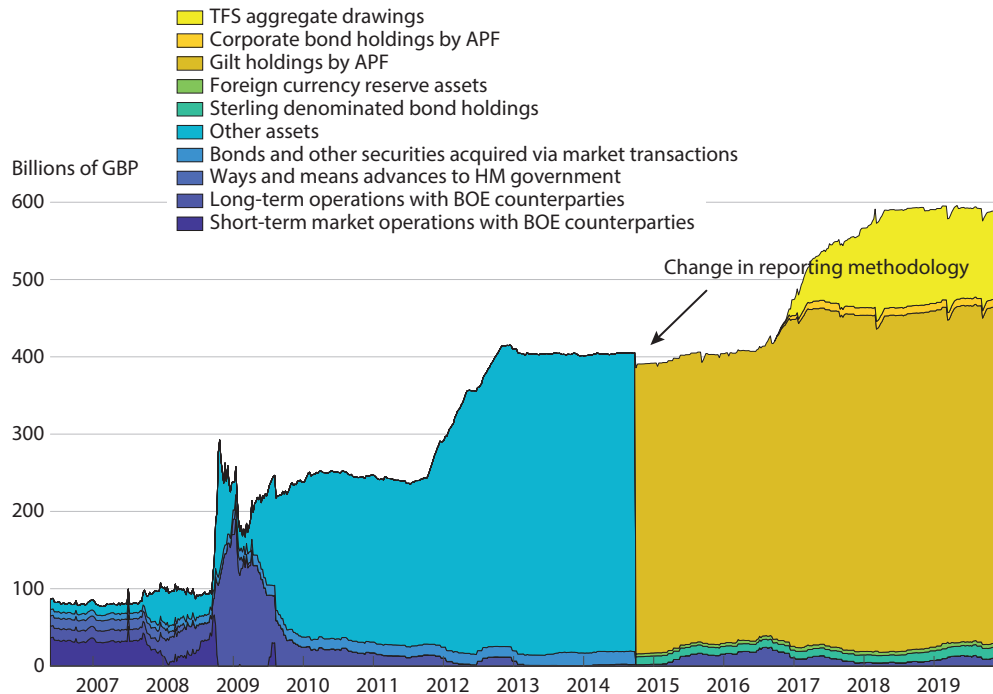
Harold MacMillan, former U.K. Prime Minister: “Events, dear boy, events.”

—Quoted (probably apocryphally) in Knowles (2006, pp. 77-78)

The Brexit vote produced great economic uncertainty and caused many analysts to revise down their forecasts for U.K. growth. The pound depreciated sharply after the referendum, as the U.K. business activity index dropped from 52.3 to 47.4 in July, the largest drop in the index’s history (Cunningham, 2016).

Facing threats to growth and price stability, on August 4, 2016, the BOE cut its policy rate from 0.5 percent to 0.25 percent, expanded its APF, and introduced the Term Funding Scheme (TFS), a conditional credit program that lent directly to banks against collateral. The BOE expanded its APF by £10 billion (\$13 billion) in U.K. corporate bonds and £60 billion (\$78 billion) in U.K. government bonds, raising the facility’s total holdings from £375 billion in July 2016 to £445 billion in May 2017 (\$488 billion to \$566 billion), when purchases concluded. The BOE funded both the TFS and the expanded APF by money creation.

The TFS—like its companion, the FLS, which would operate until January 2018—used both quantity and price incentives to encourage banks to lend to the U.K. nonfinancial sector.

Figure 14**Bank of England Assets**

NOTE: GBP, British pound. In October 2014, the BOE replaced the “Bank Return” with the “Weekly Report” as its report of weekly balance sheet statistics. The new form still contains “balance sheet items that affect monetary conditions,” but it omits items “which have the scope to inadvertently reveal the provision of covert liquidity support” (BOE, 2014, p. 339) Prior to the reporting methodology switch, APF holdings are included in “Other assets.”

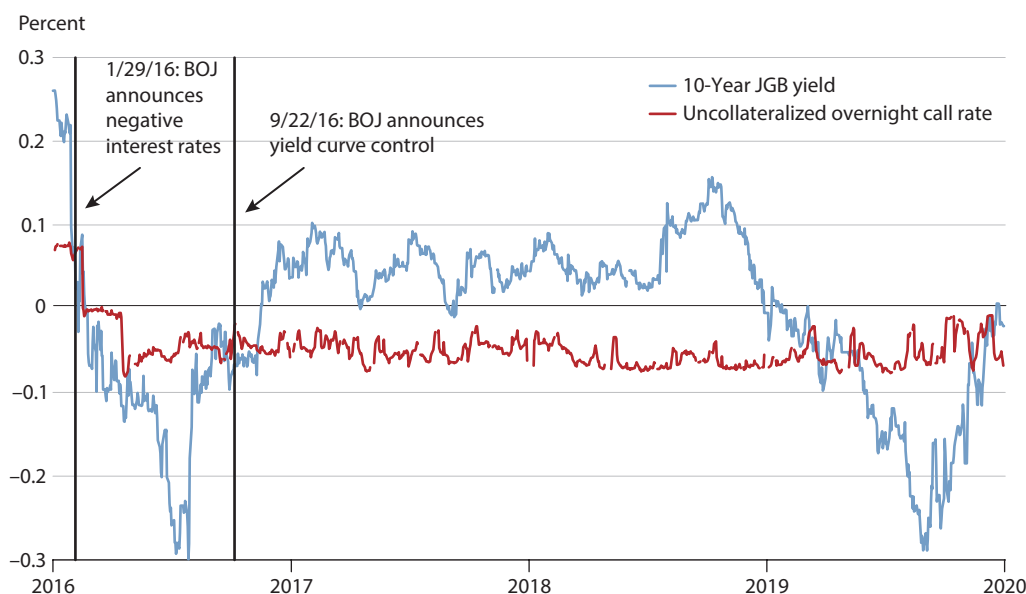
SOURCE: BOE.

Unlike the FLS, the TFS directly lent money rather than government securities.⁴⁷ The BOE designed the TFS to reduce long-term borrowing costs and to insure banks “against the risk that conditions tighten in bank funding markets.”⁴⁸ The TFS initially limited borrowing to 5 percent of banks’ outstanding loans to the U.K. nonfinancial sector. Increases in lending would raise banks’ borrowing limits on a one-for-one basis. The TFS’s interest rate incentive structure mirrored that of the FLS’s, with higher borrowing rates for banks with declining loan volumes.⁴⁹

As of January 2018, the TFS had lent U.K. banks over £100 billion (\$130 billion), about 5 percent of U.K. GDP, making it larger than the FLS at its peak. Figure 6 shows the value of TFS peaked at over 6 percent of U.K. GDP in early 2018. The post-Brexit-vote easing—that is, new asset purchases, along with TFS loans—expanded the BOE’s balance sheet from around £400 billion in June 2016 to £590 billion (\$544 billion to \$791 billion) in August 2018 (Figure 14).

6.6 The BOJ Targets the Yield Curve: September 2016

Despite the BOJ’s introduction of negative deposit rates in January 2016 and the modest stimulus following the Brexit vote, expectations of Japanese inflation continued to be undesir-

Figure 15**Japanese 10-Year Bond Yields Before and After YCC**

SOURCE: BOJ and Haver Analytics.

ably low. Meanwhile, long-term interest rates in Japan fell markedly below short-term rates in the months following the BOJ's announcement of negative interest rates. In July 2016, for example, the yield on 10-year JGBs averaged around 22 basis points below the uncollateralized overnight rate. This yield curve inversion threatened the profitability of Japanese banks, which make loans at long-term rates and borrow at short-term rates.

The BOJ announced on September 22, 2016, that it would target the uncollateralized overnight rate and the 10-year JGB yield at -0.1 percent and 0.0 percent, respectively, to avoid “destabilizing the financial system through downward pressure on financial institutions’ profits” and to further guide the economy towards price stability (Nakaso, 2017, p. 7). This new policy, which the BOJ termed QQE with Yield Curve Control (YCC), was unprecedented in recent history.⁵⁰ While the Fed, ECB, and BOE had all attempted to influence long-term yields through unconventional policies, the BOJ became the first to explicitly target longer-dated yields. To stoke inflation expectations, Governor Kuroda also announced an “inflation-overshooting commitment,” stating that the BOJ would maintain its asset purchase pace until year-over-year inflation “exceeds the price stability target of 2 percent and stays above the target in a stable manner.”⁵¹

Figure 15 illustrates that the JGB 10-year yield remained consistently above the overnight rate in the two years following the announcement of YCC, averaging 4 basis points and ranging from -10 basis points to 15 basis points. QQE with YCC marked another policy shift for the BOJ, moving the bank from “QQ targeting” back to interest rate targeting. But yield curve targeting required continued purchases of large amounts of JGBs, although at a slower pace.

BOJ holdings of JGBs increased by roughly ¥63 trillion (\$562 billion) in the 12 months following the YCC announcement, compared with ¥78 trillion (\$718 billion) over the prior year.

The BOJ's ability to successfully control long yields may depend on its ownership of a large fraction of the stock of JGBs and purchases of an even larger portion of issuance. For example, in December 2016, the BOJ owned ¥350 trillion JGB, or 39.1 percent of the ¥895 trillion JGB market. Over the next year, the JGB market grew to ¥928 trillion, while BOJ holdings grew to ¥407 trillion, or 43.9 percent of the market. That is, the BOJ's holdings increased by ¥57 trillion, while the stock of JGBs only increased by ¥33 trillion over the course of 2017. The BOJ bought almost twice the net issuance of JGBs.

The BOJ added several minor measures in 2018 and 2019, such as extending deadlines for new applications to lending programs and modifying its interest rate policy and FG. While the BOJ reaffirmed its FG on July 31, 2018, stating “the Bank intends to maintain the current extremely low levels of short- and long-term interest rates for an extended period of time,” the central bank also loosened its control on the 10-year yield, indicating that yields “may move upward or downward to some extent” depending on economic conditions.⁵² From that BOJ announcement to December 2019, the 10-year JGB yield ranged between –30 basis points and 15 basis points. On July 30, 2019, the authority assured the public that “the Bank will not hesitate to take additional easing measures if there is a greater possibility that the momentum toward achieving the price stability target will be lost.”⁵³

6.7 The ECB and BOE Announce Removal of Accommodation in 2017-18

While the Fed announced plans to normalize its balance sheet in June 2017, improving economic conditions caused the BOE and ECB to similarly consider trimming back their stimulatory policies. By 2017, the unexpectedly solid performance of the U.K. economy in the wake of the Brexit vote seemed to reassure the BOE that it need not maintain unusual stimulus. On September 14, 2017, the MPC warned that “Some withdrawal of monetary stimulus is likely to be appropriate over the coming months.” On November 2, 2017, with inflation reaching 3 percent and unemployment having fallen to 4.2 percent, the MPC raised its policy rate by 25 basis points to 50 basis points, the first MPC rate hike in more than a decade. A few months later, on February 8, 2018, the MPC warned that monetary policy may need to be “tightened somewhat earlier and by a somewhat greater extent.” The BOE's bank rate reached 0.75 percent on August 2, 2018, as the MPC cautioned that “future increases in bank rate are likely to be at a gradual pace and to a limited extent.”⁵⁴ In keeping with this caution, the MPC kept the size of its balance sheet stable and maintained the bank rate at 0.75 percent until the COVID-19 crisis in 2020.

In April 2017, core, euro area HCPI inflation—all items less food, energy, tobacco, and alcohol—climbed above 1 percent for the first time in more than a year, while real GDP growth registered above 2 percent for two straight quarters (2017:Q1-2).⁵⁵ On October 26, 2017, the ECB announced it would “downsize” its long QE program.⁵⁶ Starting in January 2018, monthly APP bond purchases would shrink by half, down to €30 billion (\$35.4 billion) “until the end of September 2018, or beyond...if the outlook becomes less favorable.”⁵⁷ In June 2018, the ECB Governing Council took another step toward normalization by clarifying that, so long

Table 4

Asset Purchase Program Size

	Program	Initial announcement date	Peak size (billion NC)	Peak size (billions of USD using average FX rate, 2008-19)	2008 GDP (billion NC)	Share of economy
Fed	QE1 agency debt	11/25/2008	\$175	\$175	\$14,292	1.22%
	QE1 MBS	11/25/2008	\$1,250	\$1,250		8.75%
	QE1 Treasuries	3/18/2009	\$300	\$300		2.10%
	QE2	11/3/2010	\$600	\$600		4.20%
	MEP	9/21/2011	\$667	\$667		4.67%
	QE3 MBS	9/13/2012	\$883	\$883		6.18%
	QE3 Treasuries	12/12/2012	\$775	\$775		5.42%
BOE	APF gilts	3/5/2009	£435	\$658	£1,441	30.19%
	APF commercial paper	1/19/2009	£1.97	\$3		0.14%
	APF corporate bonds	1/19/2009	£10	\$15		0.69%
ECB	CBPP	5/7/2009	€ 60	\$76	€ 9,219	0.65%
	CBPP2	10/6/2011	€ 40	\$51		0.43%
	CBPP3	9/4/2014	€ 264	\$334		2.86%
	SMP	5/10/2010	€ 220	\$278		2.39%
	OMT	9/6/2012	€ 0	\$ 0		0.00%
	ABSPP	9/4/2014	€ 29	\$37		0.31%
	PSPP	1/22/2015	€ 2,109	\$2,668		22.88%
	CSPP	3/10/2016	€ 185	\$234		2.01%
BOJ	Outright purchases JGBs	12/19/2008	¥106,800	\$1,079	¥501,209	21.31%
	Outright purchases commercial paper	1/22/2009	¥3,000	\$30		0.60%
	Outright purchases corporate bonds	2/19/2009	¥1,000	\$10		0.20%
	APP JGBs	10/5/2010	¥44,000	\$445		8.78%
	APP Treasury discount bills	10/5/2010	¥24,500	\$248		4.89%
	APP commercial paper	10/5/2010	¥2,200	\$22		0.44%
	APP corporate bonds	10/5/2010	¥3,200	\$32		0.64%
	APP ETFs	10/5/2010	¥2,100	\$21		0.42%
	APP J-REITs	10/5/2010	¥130	\$1		0.03%
	QQE JGBs	4/4/2013	¥387,168	\$3,912		77.25%
	QQE ETFs	4/4/2013	¥26,707	\$270		5.33%
	QQE J-REITs	4/4/2013	¥434	\$4		0.09%

NOTE: FX, foreign exchange. NC, national currency.

SOURCE: Haver Analytics, Organisation for Economic Co-operation and Development, Fed, BOE, BOJ, and ECB.

as the medium-term inflation outlook remained favorable, it would reduce monthly asset purchases to €15 billion (\$17.7 billion) from September to December 2018, at which point it would end net purchases (see Figure 11). But the ECB also stated that it would continue to reinvest principal payments from maturing securities for “an extended period” to maintain liquidity and monetary accommodation. The Governing Council maintained policy rates but reiterated that its policy was contingent on a path for inflation close to but below 2 percent. Table 4 summarizes and compares the UMPs of the ECB and its counterparts.

Responding to downside economic risks related to the U.S.-China trade war and the Brexit process, the ECB announced TLTRO-III in March 2019 to maintain favorable credit conditions. The incentives of the third iteration of the ECB’s conditional credit program resembled those of the second. The ECB extended the maturity of TLTRO-III operations from two years to three years at its September 2019 meeting.

Facing a slow economy and undesirably low inflation in the fall of 2019, the Governing Council of the ECB acted to boost growth and price increases at its September 12, 2019, meeting. It introduced a two-tier system for the deposit facility; reduced the deposit rate to –0.5 percent; and added FG that the deposit, MRO, and lending rates would be low until projected inflation is close to but below 2 percent within its projection horizon. It also announced the November 1, 2019, restart of its APP at a monthly pace of €20 billion and added FG that it would be continued as long as necessary “to reinforce the accommodative impact of its policy rates.”⁵⁸

7 CONCLUSION

Fawley and Neely (2013) described the practice of UMP by major central banks from 2008–12. This article has extended that work by investigating how major central banks have developed and implemented such policies from 2012 through 2019 to facilitate credit transactions, encourage real activity, and maintain low and stable inflation rates.

Conventional monetary policy uses purchases of short-term assets to target short-term interest rates and influence credit conditions and real activity. This article defines UMPs to be those that seek to influence medium- and long-term interest rates, drive short-rates to negative levels, or influence credit conditions in particular markets. Central banks use broad purchases of long-term bonds and FG to influence medium and long rates, narrow asset purchases, and/or conditional bank lending programs, to influence conditions in particular markets, and negative deposit and/or lending rates to drive general short rates negative.

Central bankers developed UMPs to stimulate the economy, ease credit conditions, and respond to other economic problems when short rates were at or near the zero bound. Central banks have tailored these policies to the nature of their economies and their specific problems. For example, with a financial system that is centered on bond markets, the Fed emphasized reducing bond yields—both public and private—while the BOJ and ECB initially focused on banking credit with their bank-centric economies. The BOJ has gone further than other central banks in explicitly targeting long yields, rather than merely purchasing a pre-scheduled quantity of assets or keeping a purchase pace over time. The BOE has been an early adopter of both broad asset purchases and bank lending incentive programs. The ECB used narrow bond purchases and long-term loans to banks at negative rates to support sovereign bond markets.

The earliest UMPs closely followed lender-of-last resort actions in short-term markets, as central banks saw the need to lower borrowing costs and increase the availability of longer-term credit. In 2008-09, the Fed and BOE created large asset purchase programs and drove down medium- to long-term yields with FG in their bond-centric economies, while the ECB and BOJ pursued largely sterilized smaller asset purchase programs and elastic lending to support banks.

From 2008 through 2012, all four major central banks provided unconventional monetary accommodation to varying degrees with an assortment of programs. In contrast, from 2012 through 2019, the four major central banks faced different challenges and responded to those challenges in different ways.

In 2013-14, the Fed first reduced then removed additional monetary accommodation before gradually raising the federal funds rate in 2015-18. The BOJ went in the other direction. Following the election of Prime Minister Abe in late 2012, the BOJ substantially stepped up the aggressiveness of its monetary policies, adopting a much more determined QQE policy of asset purchases, conditional lending to banks, and a tiered system of negative deposit rates before becoming the first major central bank in modern history to explicitly target long yields.⁵⁹

The ECB was initially preoccupied with threats to price stability in both directions before moving in 2014-16 to counter undesired disinflation with more aggressive stimulatory measures, such as negative deposit rates, conditional bank lending programs, and asset purchases.

As a result of “a series of unfortunate events”—that is, the Scottish independence referendum, oil price declines, a U.K. general election, and the Brexit vote—the BOE maintained fairly steady policies from 2012 to 2016, when it resumed substantial easing in the wake of the Brexit vote.⁶⁰

Although the BOE and BOJ both responded to the Brexit vote in 2016 with additional easing, central banks moved toward normalizing monetary conditions in 2017-18. In June 2017, the Fed published plans for normalizing its huge balance sheet and the ECB soon followed with normalization plans of its own in October 2017. Likewise, in February 2018, the BOE warned that it too was considering withdrawing some unusual accommodation soon.

From 2012 through 2019, central banks learned from their earlier experiences and adapted old methods to tackle new problems. An important development was the move toward contingent asset purchases. Early asset purchase programs had been either very small and limited or announced as a lump sum, but central banks eventually moved to open-ended asset purchases whose sizes and durations depended on incoming economic data. The Fed’s QE3 was the first major asset program to be continuous, open-ended, and explicitly contingent on incoming data.⁶¹

Bank lending programs evolved too, as central banks moved from conventional lending operations to fully elastic supply to conditional programs that offer price and/or quantity incentives for greater bank lending to the nonfinancial public. The BOE created the FLS and TFS, the BOJ created the SBLF, and the ECB created the TLTRO.

In short, the 2012-19 period was a period in which central banks further developed their UMP tools to cope with heterogeneous challenges. The preparation would prove useful for the central bank responses to the 2020 COVID-19 crisis, which are described in Haas, Neely, and Emmons (2020). ■

GLOSSARY

Asset-backed securities (ABS): Securities that pay their holders the cash flows from a pool of financial assets (excluding mortgages), such as auto loans, credit card receivables, home equity loans, or student loans.¹

Asset purchase facility (APF) (Bank of England [BOE]): A BOE facility to purchase large quantities of both public and private debt, thereby reducing borrowing costs and stimulating new credit flows.

Asset purchase program (APP) [Bank of Japan (BOJ)]: A BOJ program to buy public and private assets to reduce long-term interest rates and risk premia. The APP also conducted three- and six-month fixed-rate operations (FROs): collateralized loans to banks that were disbursed in fixed, pre-determined quantities.

Asset purchase programme (APP) (European Central Bank [ECB]): An ECB program to buy a wide range of assets, such as government bonds, ABS and corporate bonds, to reduce funding costs in those markets.

Commercial paper: An unsecured, short-term debt instrument issued by corporations. Most commercial paper issued by U.S. corporates in 2016 had one- to four-day maturities, although commercial paper may have a maturity as long as 270 days.²

Corporate bonds: Debt instruments used to finance business operations. They have maturities greater than 270 days and are sometimes backed by collateral such as a company's physical assets.³

Counterparty risk (a.k.a. default risk): The danger that a party to a financial agreement (loan, interest rate swap, etc.) will fail to meet its obligations. During banking panics and financial crises, perceived counterparty risk typically rises, raising interest rates and lowering trading volumes.

Covered bonds: Bonds that permit bondholders recourse to both the collateral and the bond issuer in the event of default. Banks must hold the underlying collateral on their balance sheets, which reduces incentives to make and securitize low-quality loans. Issuing longer-maturity covered bonds helps banks mitigate the maturity mismatch that they typically face between short-term deposits and long-term loans.

Credit easing: Central bank policies that aim to lower interest rates or provide liquidity to specific credit and asset markets. Credit easing can involve asset purchases that change the composition but perhaps not the size of the central bank balance sheet.

Deposit rate: The interest rate that a central bank pays on some classes of reserves—often excess reserves—that financial institutions deposit with the central bank. A deposit rate typically establishes a floor for interest rates.

Exchange-traded funds (ETFs): Securities that trade on an exchange that track the value of a pool of stocks, bonds, or commodities. For example, ETFs that track a stock market index enable investors to diversify their portfolio with a single tradable security.

Funding for Lending Scheme (FLS): A BOE bank-loan program designed to stimulate lending and reduce borrowing rates for U.K. households and businesses. The FLS is an early example of a conditional credit program in that it used price and quantity incentives to encourage bank lending.

Growth-Supporting Funding Facility (GSFF): A BOJ program established to finance investments with special economic value. Banks could borrow from the GSFF for up to three years (four years starting in June 2014) and at low interest rates to invest in specified types of projects, including research and development, startups, healthcare, and workforce development.

Inflation: A sustained increase in the general price level of goods and services over time. Central banks consider a low and stable rate of inflation to be price stability. A similarly persistent decline in the overall price level is called “deflation.”

Liquidity risk: The chance that an asset cannot be liquidated quickly at a price close to its fundamental value. Heterogeneous assets, such as real estate, tend to be illiquid, while homogeneous assets, such as government bonds, tend to be liquid.

Loan Support Program (LSP): A BOJ program to provide long-term credit to banks to lower borrowing costs and stimulate growth. The LSP comprises the GSFF (established in 2010) and the Stimulating Bank Lending Facility (SBLF, established in 2012).

Main refinancing operations (MRO): Seven-day ECB bank loans that control liquidity to the banking system. The MRO rate is one of the main policy tools of the ECB; it benchmarks interest rates on other euro-denominated financial investments.

Monetary base: The sum of currency in circulation plus commercial bank reserves held with the central bank. It is the narrowest measure of the money supply and is frequently used to gauge the stance of monetary policy. A central

bank security purchase expands the monetary base. Conversely, selling securities to tighten policy shrinks the monetary base.

Mortgage-backed securities (MBS): A security that pays the holder using cash flows from a pool of mortgage loans. Agency MBS are guaranteed by U.S. government-sponsored enterprises (GSEs, e.g., Fannie Mae and Freddie Mac).⁴

Outright Monetary Transactions (OMTs): A program that replaced the ECB's Securities Markets Program (SMP) on September 6, 2012. The OMT program provides a framework for the ECB to conduct sterilized government bond purchases in secondary markets on an as-needed basis. In contrast to the SMP, OMTs require that countries receiving support implement fiscal reforms. The ECB has not executed any OMTs as of April 2018.

Quantitative easing (QE): A monetary policy that expands the central bank balance sheet, which is typically implemented through asset purchases. Central banks typically implement QE by purchasing long-term bonds to lower long-term interest rates when short-term interest rates approach the zero-lower bound. Any policy that substantially raises central bank assets can be considered QE, however.

Risk premium: The return on an asset that exceeds the risk-free rate of return, often measured as the interest rate on three-month U.S. Treasury bills. Risk premia compensate investors for holding many kinds of risk, for example, default risk, duration risk, liquidity risk, and prepayment risk.

Securities Markets Program (SMP): A discontinued ECB program to support the debt of fiscally stressed countries by buying their sovereign debt in secondary markets. The ECB conducted fully sterilized SMP purchases on an ad hoc basis. On September 6, 2012, the ECB replaced the SMP with the OMT program.

Special funds-supplying operations (SFSOs): BOJ operations that offered unlimited three-month collateralized loans to banks at the uncollateralized overnight call rate. The BOJ replaced SFSOs with fixed-rate operations on December 1, 2009.

Sterilization: The process by which a central bank prevents monetary policy actions (e.g., asset purchases) from affecting the monetary base by conducting countervailing operations. For example, the Federal Reserve's early long-term asset purchases through its Maturity Extension Program were offset by sales of short-term assets. Unsterilized asset purchases are funded by issuing central bank reserves, that is, money creation.

Stimulating Bank Lending Facility (SBLF): A BOJ conditional credit program that offers banks the incentive of greater loans from the central bank in exchange for raising their loans to the nonfinancial sector. The BOJ makes SBLF loans available for one- to four-year periods at the uncollateralized overnight call rate.

Targeted Longer-Term Refinancing Operations (TLTRO): ECB low-interest loans to banks at maturities of up to four years. The TLTRO rewarded banks for increasing their loan activity by raising borrowing limits 3 percent for every 1 percent increase in nonfinancial lending. The ECB introduced the TLTRO program—its first conditional credit program—on June 5, 2014, and then replaced it with TLTRO II on March 10, 2016.

Targeted Longer-Term Refinancing Operations II (TLTRO II): ECB loans that replaced the TLTRO on March 10, 2016. TLTRO II aimed to stimulate new credit flows to the economy by linking interest payments on borrowed funds to increases in lending activity. Interest rates on TLTRO-II loans started at the MRO rate (0 percent) and declined to as low as the ECB deposit rate (−0.4 percent) if a bank increased its lending activity by 2.5 percent. The TLTRO-II program concluded in March 2017.

Targeted Longer-Term Refinancing Operations III (TLTRO III): ECB loans introduced in March 2019 and similar to TLTRO II. At first, banks could borrow funds for up to two years, but in September 2019, the ECB increased the maximum maturity to three years. The interest rate on TLTRO-III funds for a bank would begin at the MRO rate (0 percent) and could decline to as low as the deposit rate (−0.5 percent) if the participating bank increased its lending activity by 2.5 percent.

Term Funding Scheme (TFS): The BOE's second conditional credit program. The BOE established the TFS program to ease conditions following the Brexit referendum in June 2016. The TFS functioned similarly to the FLS: The BOE would fund 100 percent of any net increases in banks' lending to U.K. households and businesses, and any banks that reduced loan activity would pay a higher interest rate on borrowed funds.

Notes

¹ For information on ABS outstanding, see Fed (2020a).

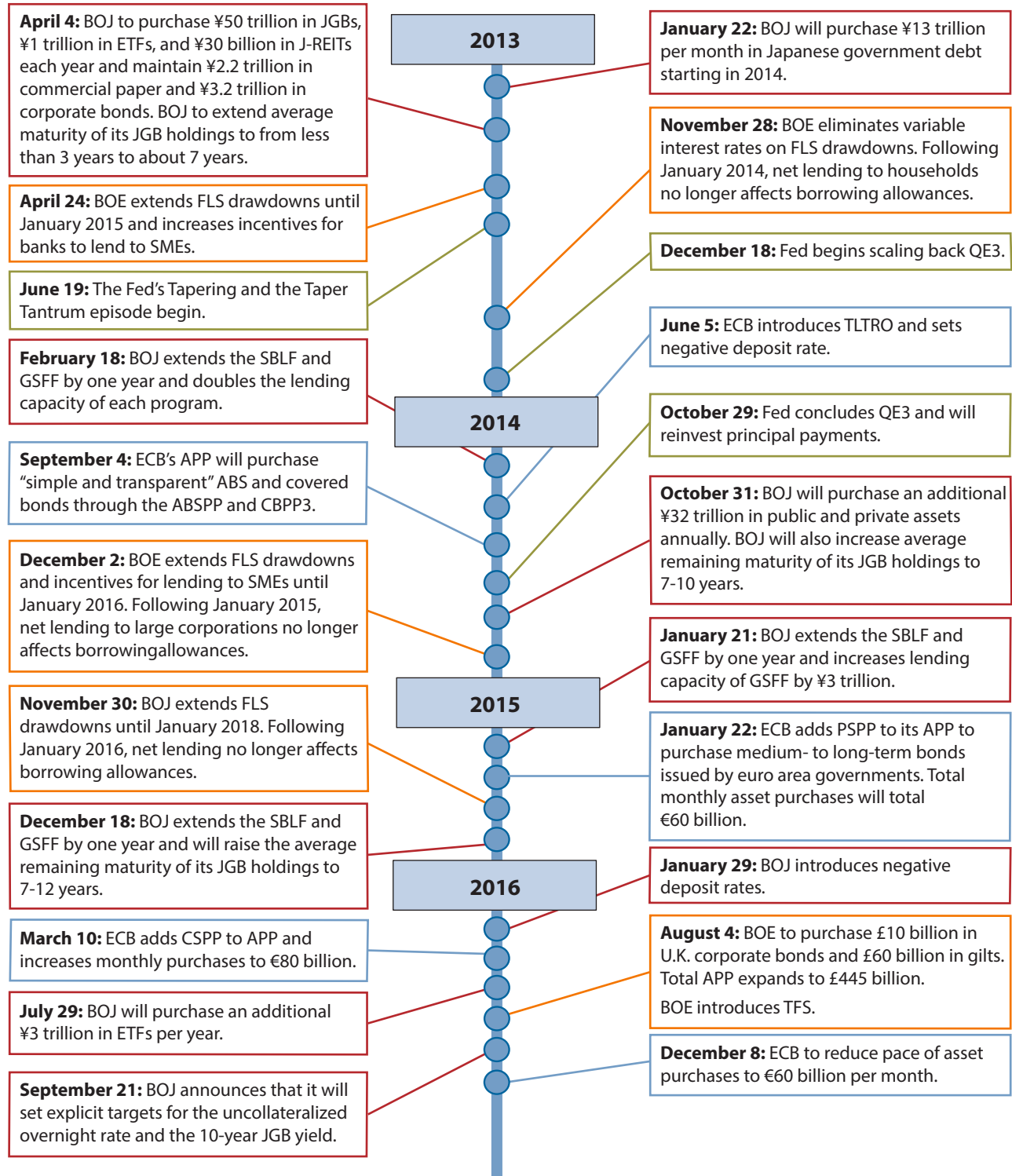
² For information on commercial paper issuance, see Fed (2020d).

³ For information on new U.S. corporate bond issues, see Fed (2020c).

⁴ For information on agency- and GSE-backed securities outstanding, see Fed (2020b).

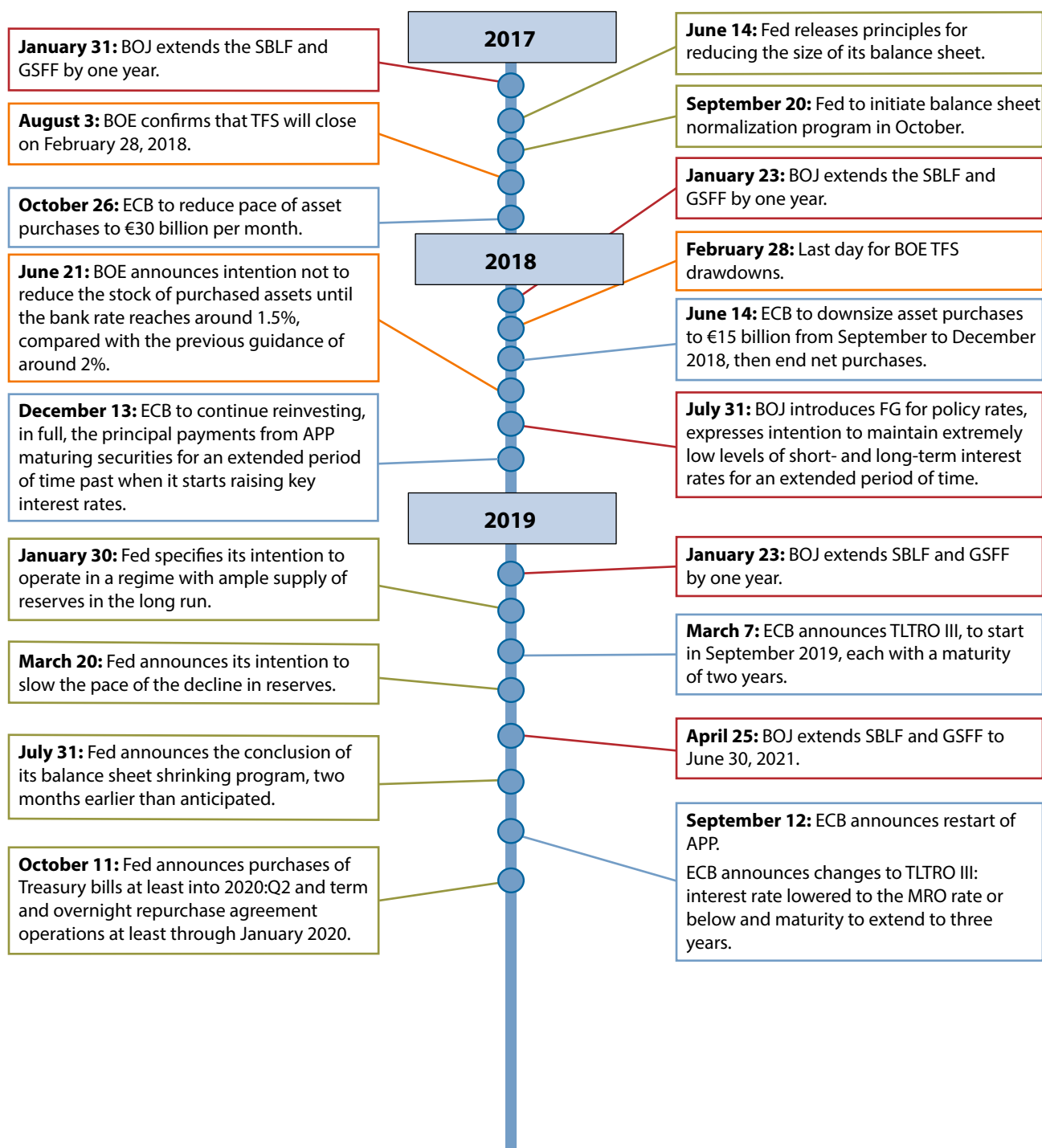
Appendix A

Timeline



Appendix A, cont'd

Timeline



APPENDIX B

Forward Guidance Tables

Table B1.A

Federal Reserve Statements on Forward Guidance

Date	Statement
12/16/2008	Expects low rates “for some time.”
3/18/2009	Expects low rates “for an extended period.”
9/13/2012	Expects low rates “at least through mid-2015.”
12/12/2012	Expects low rates to be appropriate while unemployment is above 6.5% and inflation is forecasted below 2.5%.
12/18/2013	Expects low rates “well past the time that the unemployment rate declines below 6.5 percent.”
3/19/2014	Expects low rates “for a considerable time after the asset purchase program ends.”
10/29/2014	Expects “to maintain the 0 to ¼ percent target range for the federal funds rate for a considerable time following the end of its asset purchase program.”
12/17/2014	“[J]udges that in can be patient in beginning to normalize the stance of monetary policy.”
3/18/2015	Expects an increase in the target range will be appropriate when it has “seen further improvement in the labor market and is reasonably confident that inflation will move back to its 2 percent objective.”
7/29/2015	Changes that it expects an increase in the federal funds rate when it sees “further improvement” in the labor market to when it sees “some further improvement.”
10/28/2015	Notes that it will be “determining whether it will be appropriate to raise the target range at its next meeting.”
12/16/2015	Expects that economic conditions will “warrant only gradual increases in the federal funds rate; the federal funds rate is likely to remain, for some time, below levels that are expected to prevail in the longer run.”
3/15/2017	Changes that economic conditions will “warrant only gradual increases” in the federal funds rate to that they will “warrant gradual increases.”
1/31/2018	Changes that economic conditions will “warrant gradual increases” in the federal funds rate to that they will “warrant further gradual increases.”
6/13/2018	No longer states that the federal funds rate is “likely to remain, for some time, below levels that are expected to prevail in the longer run.”
9/26/2018	Drops a sentence indicating that “the stance of monetary policy remains accommodative.”
1/30/2019	No longer indicates that some further gradual increases will be warranted, instead stating that it “will be patient as it determines what future adjustments to the target range” are appropriate.
6/19/2019	Will “closely monitor the implications of incoming information for the economic outlook and will act as appropriate to sustain the expansion.”

Table B1.B**European Central Bank Statements on Forward Guidance**

Date	Statement
7/4/2013	Expects rates at current or lower levels for “an extended period of time.”
8/1/2013	“Confirms that it expects” current or lower rates for an extended period.
1/9/2014	“Firmly reiterates” expectations of current or lower rates for an extended period.
3/10/2016	Expects rates at current or lower levels well past the horizon of net asset purchases.
6/8/2017	Expects rates at current levels well past the horizon of net asset purchases.
6/14/2018	Expects rates to remain at their present levels at least through the summer of 2019 or “for as long as necessary to ensure that the evolution of inflation remains aligned with the current expectations of a sustained adjustment path.”
7/26/2018	Expects rates to remain at their present levels at least through the summer of 2019 or “for as long as necessary to ensure the continued sustained convergence of inflation to levels that are below, but close to, 2% over the medium term.”
3/7/2019	Expects rates to remain at their present levels at least through the end of 2019 or “for as long as necessary to ensure the continued sustained convergence of inflation to levels that are below, but close to, 2% over the medium term.”
6/6/2019	Expects rates to remain at their present levels at least through the first half of 2020 or “for as long as necessary to ensure the continued sustained convergence of inflation to levels that are below, but close to, 2% over the medium term.”
7/25/2019	Expects rates to remain at their present or lower levels at least through the first half of 2020 or “for as long as necessary to ensure the continued sustained convergence of inflation to its aim over the medium term.”
9/12/2019	Expects rates to remain at present or lower levels “until it has seen the inflation outlook robustly converge to a level sufficiently close to, but below, 2% within its projection horizon.”

Table B1.C**Bank of England Statements on Forward Guidance**

Date	Statement
8/7/2013	Will keep rates low until unemployment falls to 7%.
2/12/2014	Will consider multiple factors before raising rates. Expects bank rate to rise ultimately to a level “appreciably below” pre-recession average.
9/14/2017	“Some withdrawal of monetary stimulus is likely to be appropriate over the coming months.”
2/8/2018	Expects monetary policy may need to be tightened quicker and to a greater extent than previously expected.
3/22/2018	States that “an ongoing tightening of monetary policy over the forecast period will be appropriate” to return inflation to its target.
12/20/2018	Adds that “the monetary policy response to Brexit, whatever form it takes, will not be automatic and could be in either direction.”
6/20/2019	Adds that an ongoing tightening of monetary policy would be appropriate if the economy developed in line with inflation projections that “included an assumption of a smooth Brexit.”
8/1/2019	Adds that an increase in interest rates would be appropriate “assuming a smooth Brexit and some recovery in global growth.”
9/19/2019	States that in the event of a no-deal Brexit, “the monetary policy response would not be automatic and could be in either direction,” while in the event of a smooth Brexit and some global growth recovery, limited increases in interest rates at a gradual pace would be appropriate.

Table B1.D**Bank of Japan Statements on Forward Guidance**

Date	Statement
4/13/1999	Zero interest rates until “deflationary concerns are dispelled.”
10/10/2003	Will maintain QE policy until inflation is positive for a few consecutive months.
10/5/2010	Zero interest rates until “price stability is in sight.”
2/14/2012	Zero interest rates until “1 percent inflation is in sight.”
1/22/2013	Open-ended purchasing with a 2 percent price stability target.
4/4/2013	Will continue QQE until inflation stably reaches 2%, notes time horizon of about two years.
9/22/2016	Will continue QQE w/yield curve control until inflation reaches and stays above 2%.
7/31/2018	Will maintain the current extremely low levels of short- and long-term interest rates for an extended period of time.
4/25/2019	Will maintain the current extremely low levels of short- and long-term interest rates for an extended period of time, at least through around spring 2020.
7/30/2019	“[W]ill not hesitate to take additional easing measures if there is a greater possibility that the momentum toward achieving the price stability target will be lost.”
9/19/2019	“[I]t is becoming necessary to pay closer attention to the possibility that the momentum toward achieving the price stability target will be lost.”
10/31/2019	Expects rates to remain at present or lower levels “as long as it is necessary to pay close attention to the possibility that the momentum toward achieving the price stability target will be lost.”

NOTES

- ¹ In practice, several central banks have pushed short-term interest rates below zero. While this strategy has potential benefits, it also has potential costs, and so the use of negative interest rates has been limited.
- ² Many central banks influence general short-term interest rates by setting the interest rate that the central bank pays on reserves (IOR) and the interest rate that the central bank charges borrowers, that is, the lending rate. The IOR functions as a floor for interest rates because banks would not lend to private parties at a rate lower than they could lend to the central bank. Similarly, commercial banks would not borrow at a rate greater than the rate at which they could borrow from the central bank. Such a system is called a corridor system (Keister, 2012), and moving it influences all short-term interest rates.

In practice, this argument does not always hold. For example, in the United States there are institutions that cannot deposit money with the Fed and so they are willing to lend at rates below the IOR rate. Similarly, banks may be reluctant to borrow from a central bank for regulatory reasons under some systems.
- ³ At a press conference on April 13, 1999, Governor Hayami originally committed to a ZIRP until deflationary concerns subside and reiterated that commitment in a speech on June 22, 1999 (Hayami, 1999).
- ⁴ The term for Japanese bank reserves is often translated as “current accounts,” a term that is more commonly used for international trade. In this article, we will refer to the quantity of bank reserves to avoid confusion.
- ⁵ In this article, we often approximate foreign currency amounts in dollars using an exchange rate from the year of the announcement or program discussed. Therefore, the conversion rate will change with the period discussed. Such inexact calculations are only intended to provide gross perspective of the amounts in dollars.
- ⁶ See Spiegel (2006) and Shiratsuka (2009).
- ⁷ A country’s monetary base is made up of reserves held with the central bank and currency in circulation. The monetary base is a liability of the central bank. The accounting counterpart of the monetary base is the total assets of the central bank, that is, the assets that the central bank has purchased to create the monetary base.
- ⁸ These measures included currency swap lines with foreign central banks, the Term Auction Facility (TAF) in December 2007 to get liquidity directly to banks; the Term Securities Lending Facility (TSLF) to provide Treasuries as collateral for financial markets in March 2008; the Primary Dealer Credit Facility (PDCF) in March 2008; Maiden Lane LLC I, II, and III to hold risky assets from Bear Sterns and AIG; the Asset-Backed Commercial Paper Money Market Mutual Fund Lending Facility (AMLF) in September 2008; the Commercial Paper Funding Facility (CPFF) and Money Market Investor Funding Facility (MMIFF) in October 2008; and the Term Asset-Backed Securities Loan Facility (TALF) in November 2008.

In addition to these Fed actions, other regulatory and governmental authorities took action to relieve financial market distress. On September 7, 2008, the Federal Housing Finance Agency (FHFA), placed Fannie Mae and Freddie Mac into conservatorship. In October 2008, the FDIC established the Temporary Liquidity Guarantee Program (TLGP) to facilitate interbank lending. In early 2009, the U.S. Treasury created the Making Home Affordable support program to help homeowners avoid foreclosure.
- ⁹ The Dodd-Frank Act (2010) now prohibits the Fed from making special loans to just one firm. Instead, any loan facility must be available to a class of borrowers and the loan facilities must not extend credit to insolvent firms.
- ¹⁰ The FOMC regularly used FG long before other unconventional policy tools. In 1994-95, the FOMC began to announce funds rate target changes and issue statements immediately after FOMC meetings and it almost eliminated intermeeting target changes, which had previously been common. The FOMC took further steps in the following years: It added a statement of bias—the likely direction of its next move in May 1999 and then replaced that with a balance of risks statement, characterizing likely risks to growth or inflation, in January 2000. From August 2003 to December 2005, the FOMC often offered FG about the future path of the funds target in statements. The Board of Governors provides a timeline of FG at <https://www.federalreserve.gov/monetarypolicy/timeline-forward-guidance-about-the-federal-funds-rate.htm>.
- ¹¹ The Bank for International Settlements reports statistics on debt securities outstanding. One can access these data at <https://stats.bis.org/>.
- ¹² On February 14, 2012, the BOJ again promised zero interest rates until “1 percent inflation is in sight” (BOJ, 2012).
- ¹³ See the 7/13/2012 BOE press release. See Table 2C.

- ¹⁴ See the 4/24/2013 BOE press release. See Table 2C.
- ¹⁵ On 12/2/2014, the BOE extended the FLS to January 2016 and, on 11/30/2015, it extended it to January 2018.
- ¹⁶ See Fed (2012).
- ¹⁷ See the 12/12/2012 Fed press release. See Table 2A.
- ¹⁸ See the 12/12/2012 Fed press release. See Table 2A.
- ¹⁹ Tighter-than-expected monetary policy causes domestic currency to appreciate.
- ²⁰ See the 12/18/2013 Fed press release. See Table 2A.
- ²¹ Neely (2013) discusses why central banks in developed nations are generally given operational independence to achieve goals set by political leaders and are accountable for their performance.
- ²² Andolfatto and Li (2014) briefly document and evaluate the history of Japanese QE.
- ²³ See the 4/4/2013 BOJ press release. See Table 2D.
- ²⁴ QE1 increased the Fed's balance sheet by about 12 percent of GDP over a period of 18 months.
- ²⁵ See the 10/31/2014 BOJ press release. See Table 2D.
- ²⁶ See the 1/21/2015 BOJ press release. See Table 2D.
- ²⁷ See ECB (2014a).
- ²⁸ In 1998, the ECB Governing Council quantified its definition of price stability as "a year-on-year increase in the Harmonised Index of Consumer Prices (HICP) for the euro area of below 2%" (ECB, n.d.a). In 2003, the Governing Council clarified that "it aims to maintain inflation rates below, but close to, 2% over the medium term" (ECB, n.d.a).
- ²⁹ See, for example, the 1/22/2015 ECB press conference. See Table 2B.
- ³⁰ Bhattarai and Neely (forthcoming) detail the literature on negative interest rates.
- ³¹ See the 6/5/2014 ECB press release. See Table 2B.
- ³² Conventional wisdom is that interest rates cannot become (very) negative because people and banks would just hold cash rather than pay to hold bank deposits. Garbade and McAndrews (2012) and Anderson and Liu (2013) discuss problems related to imposing negative interest rates. The August 2010 FOMC meeting transcript very briefly mentioned a 2010 Board of Governors of the Federal Reserve System memo, Burke et al. (2010), that considered the implications of negative short rates for the U.S. economy. In its September 2011 meeting, the FOMC briefly considered the possibility that lowering the interest rate on excess reserves (IOER) would produce slightly negative rates in some money market rates. Neely (2020) discusses the issues surrounding the use of negative interest rates in the United States.
- The banking system as a whole cannot "lend out" reserves, because the total quantity of reserves is determined by decisions of the central bank and the cash/deposit preference of individuals, but banks with excess reserves—reserves in excess of legal requirements—can make loans and thereby convert excess reserves to required reserves.
- ³³ ABSPP would also include purchases of MBS. See the 9/4/2014 ECB press release. See Table 2B.
- ³⁴ QE consists of asset purchase and lending programs that unusually increase bank reserves, which are liabilities of the central bank. Credit easing programs can also increase bank reserves but focus on altering the composition of central bank assets to affect credit market conditions (Bernanke, 2009).
- ³⁵ See the 1/22/2015 ECB press release. See Table 2B. The ECB's APP-related announcements cumulatively lowered 10-year euro area yields by 30 to 50 basis points, and the announcements had larger effects on Italian and Spanish yields than on German yields (Altavilla, Carboni, and Motto, 2015).
- ³⁶ Looser-than-expected monetary policy causes the domestic currency to depreciate.
- ³⁷ See Fed (2015).
- ³⁸ In the face of incipient weakness in the summer of 2019, the FOMC began to lower the target rate/IOER again, with the rate reaching 1.75 percent in November 2019. The other central banks had not gone nearly so far as the Fed toward "normal" monetary policy and so did not have scope for conventional easing in 2019.

- ³⁹ A bank's deposits with the BOJ would be organized into three categories: (i) Macro Add-on Balance, (ii) Basic Balance, and (iii) Policy Rate Balance, which would entail interest rates of 0.0 percent, 0.1 percent, and -0.1 percent, respectively. The Macro Add-on Balance would include required reserves along with any amounts borrowed through the SBLF or the GSFF. The Basic Balance would contain reserves up to a bank's average reserves held in 2015 minus its Macro Add-on Balance. And lastly, the Policy Rate Balance would comprise any reserves in excess of the Macro Add-on and Basic Balances (see BOJ, 2016b).
- ⁴⁰ See the 1/29/2016 BOJ press release. See Table 2D and BOJ (2016b).
- ⁴¹ Just one example would be the Fed's Policy Normalization Principles, which have been modified multiple times since they were initially released after the September 2014 FOMC meeting (Fed, 2019).
- ⁴² See the 12/3/2015 ECB press release. See Table 2B.
- ⁴³ See the 3/10/2016 ECB press release. See Table 2B.
- ⁴⁴ In April 2020, the BOJ would decide to offer to pay 0.1 percent to banks that participate in its new SFSOs (Kihara, Canepa, and Schneider, 2020).
- ⁴⁵ See the 3/10/2016 ECB press release. See Table 2B.
- ⁴⁶ See the 7/29/2016 BOJ press release. See Table 2D.
- ⁴⁷ The BOE had greatly modified the FLS between July 2012 and the last drawdown in January 2018. Specifically, the BOE had stripped out most of the incentives in the FLS.
- ⁴⁸ See the 8/4/2016 BOE press release. See Table 2C.
- ⁴⁹ Participants would pay a baseline fee of 25 basis points as well as a "scheme fee," that is, an additional 5 basis points for every 1 percent its outstanding loans declined over the course of the program. The BOE set a 25-basis-point maximum for the scheme fee but would drop the fee to zero if a bank exhibited neutral or positive net lending.
- ⁵⁰ Prior to the U.S. Treasury-Fed accord of 1951, the U.S. Treasury and Fed had cooperated to effectively fix long-term interest rates to hold down the costs of financing World War II (Romero, 2013).
- ⁵¹ See the 9/21/2016 BOJ press release. See Table 2D.
- ⁵² See the 7/31/2018 BOJ press release. See Table 2D.
- ⁵³ See the 7/30/2019 BOJ statement. See Table B1.D in Appendix B.
- ⁵⁴ Respective quote citations: BOE (2017). BOE (2018). See the 8/2/2018 BOE press release. See Table 2C.
- ⁵⁵ Unlike the Fed, which has a dual mandate of price stability and maximum sustainable employment, the ECB has a single mandate—price stability—with the ECB Governing Council told it "should avoid generating excessive fluctuations in output and employment if this is in line with the pursuit of its primary objective" (ECB, n.d.b).
- ⁵⁶ President Draghi was emphatic in October that the policy change be termed "downsizing" rather than "tapering" (ECB, 2017a).
- ⁵⁷ See the 10/26/2017 ECB press release. See Table 2B.
- ⁵⁸ See the 9/12/2019 ECB press release. See Table 2B.
- ⁵⁹ Central banks sometimes targeted long yields in previous eras. During and shortly after World War II, for example, the U.S. Treasury and Fed cooperated to maintain low interest rates to reduce the costs of financing the war.
- ⁶⁰ We borrow from Forbes (2017, p. 4) the phrase "a series of unfortunate events" to describe the reasons for the BOE's inactivity in 2012-16.
- ⁶¹ The ECB's earlier and much smaller SMP did not specify an amount or a pace of purchases but was conducted in an ad hoc fashion, conditional on market developments.

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Neely and Karson

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Neely and Karson

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