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Shall we twist?*

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Abstract

We study the implementation and effectiveness of Operation Twist, which represents the origin of today's unconventional monetary policy measures. Operation Twist serves as a perfect laboratory to assess the usefulness of such balance sheet policies because at that time interest rates were not at their lower bound and the economy was not in a historic turmoil. We assess the actions of the Fed and the Treasury under Operation Twist based on balance sheet data and evaluate the success of the operation using modern time series techniques. We find that the joint policy actions, despite being of rather moderate scale, were effective in compressing the long-short spreads of Treasury bond rates.

JEL Classification: C22, E43, E52, E63, E65
Keywords: Operation Twist, Monetary Policy, Interest Rates, Yield Curve, Time Series

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1 Introduction

In the aftermath of the Great Recession, many advanced economies have experienced very low interest rates. With policy rates approaching their effective lower bounds, central banks around the world could no longer rely on conventional policy instruments to control price stability and to stabilize the economy. Instead, they have introduced unconventional measures such as the extension and restructuring of their balance sheets, often referred to as quantitative easing (QE). In fact, such measures are not completely new. The United States experienced a comparable situation in the early 1960s. At that time, the U.S. economy was recovering from a recession and the Kennedy administration, which took office in January 1961, wanted to stimulate the economy with the help of easier monetary and fiscal policy. However, the Federal Reserve System (Fed) was unwilling to lower short-term interest rates. Although interest rates had not been restricted by the effective lower bound, the Fed's monetary policy leeway was constrained because of a growing differential between U.S. and European interest rates, which had led to increased outflows of dollars and gold towards Europe under the institutional setting of the Bretton Woods system.

Under Bretton Woods the U.S. dollar acted as a global reserve currency and could be exchanged for gold at a fixed rate. The dollar outflows mainly had two causes: (i) an increasing interest rate differential between European and U.S. rates, leading to a surge of capital outflows and (ii) a deterioration of the U.S. balance of payments due to weaker U.S. exports and stronger imports. The Fed judged the level of gold outflows as a systemic risk that had to be brought under control. Therefore, stimulating the economy by lowering short-term interest rates was not an option. Given this limitation, the Kennedy administration needed to find novel ways to provide monetary stimulus for the economy. The proposed solution came in the form of Operation Twist (OT): an attempt in cooperation with the Fed to twist the yield curve and narrow the spread between long- and short-term interest rates. The plan was the following: Under OT, the Treasury would issue short-term securities instead of long-term securities and the Fed would swap short-term for long-term government bonds, thus restructuring the composition of the asset side in its balance sheet. These operations would lead to an increase in the relative supply of short-term securities, which was expected to exert upward pressure on short-term rates. Simultaneously, the corresponding decrease in the relative availability of long-term securities was expected to lower long-term yields, thus twisting the term structure in the desired direction (Modigliani and Sutch, 1966). Long-term interest rates were seen as the main determinant of investment at that time, and the goal of lowering them was to stimulate the economy by increasing the flow of private investment.

In this paper, we assess the implementation of OT using balance sheet data on the Fed's and the Treasury's positions of government securities, which reveal information on the respective actions undertaken by the two authorities. Furthermore, we use an econometric approach to investigate the operation's success in compressing the yield curve for government securities. We see OT as a perfect laboratory to study the effect of such balance sheet operations, for two reasons (i) The idea of using the composition of the central bank's balance sheet as a monetary policy instrument, and the intended effects of this unconventional policy were the same in the 1960s as they have been in the aftermath of the Great Recession, but in contrast to the recent period, interest rates during OT were not restricted by their effective lower bound. Moreover, (ii) the economy at that time was not in a historic turmoil, which makes it easier to isolate the effect of such policies. The existing literature on OT is rather scarce. However, two studies stand out: an early paper by Franco Modigliani and Richard Sutch (1966), who evaluate the success of the new policy measure, and a more recent study by Eric Swanson (2011), who readdresses the same question using modern event study techniques. Both studies come to the conclusion that if OT had an effect on the yield curve, it was rather moderate. However, both studies have some important limitations. Modigliani and Sutch estimate a distributed lag regression model of the spread of long-term and short-term rates on the 3-month Treasury bill rate using quarterly data for the period 1952Q1 to 1961Q4. They then perform a counterfactual exercise for the period from 1962Q1 to 1965Q2 based on these estimates. This setup has two (potential) problems. First, and less importantly, they are working with data at quarterly frequency even though all the time series included in their analysis are available at monthly frequency. This additional aggregation hence seems unnecessary and might have influenced the outcome of their investigation. Second, and more importantly, their definition of the OT period is highly debatable since OT had already started in February 1961 when Kennedy announced the program. Thus, including data from 1961 in the reference sample might exert a downward bias on the detected effects of OT. Swanson, on the other hand, focuses on six major announcements containing news about OT and their effects on long-term rates within a narrow window of 1-4 days. The last event he considers is in April 1961. However, taking a closer look at the balance sheet data reveals that most of the action undertaken by the Fed took place solely afterwards (see Figure 1). Thus, Swanson captures the announcement effects of OT, but he cannot provide evidence on the actual policy effects, i.e., the impact of changes in the supply of securities outstanding. Moreover, the event study cannot provide any evidence on the impact of OT more than a few days after the announcement. For the evaluation of policy actions, however, their impact after a few months or even years is of particular interest.

Our empirical analysis of OT is in fact very similar to the one in Modigliani and Sutch (1966, 1967). However, as we use data at a higher frequency (monthly instead of quarterly), apply modern methods and study the balance sheet data our analysis is more thorough and our estimates are more precise. In the spirit of Modigliani and Sutch, we estimate an autoregressive distributed lag (ARDL) model at monthly frequency in which we regress different long-short spreads on lagged values of themselves and a set of explanatory variables controlling for the state of the economy. Instead of evaluating the effects of OT by comparing the actual development of the spreads with the predicted development extrapolated from the model under the pre-OT period, we focus on the residuals of the estimated model. Under the null hypothesis that OT had no impact on the spreads, the residuals are assumed to be normally and hence symmetrically distributed around zero over the whole sample period. If, on the other hand, OT was able to compress the long-short spreads, we expect the residuals to be tilted towards negative values during the OT period. The cumulative sum of the errors proves to be a handy measure to detect such an asymmetry. We therefore sum the monthly errors starting in February 1961, when OT was publicly announced for the first time, and compare them to the bootstrapped confidence bands under the null hypothesis of no yield spread compression. If the cumulative errors are below the 10th percentile of the bootstrapped cumulative errors, we consider OT to have been successful in compressing the yield spread. In a simulation study, we show that the method we propose is able to capture such a shock to the yield spreads.

Our main findings can be summarized as follows. OT was a policy operation initiated and promoted by the Kennedy administration, and highly disputed within the Fed. The joint policy actions undertaken by the Treasury and the Fed were rather moderate and did not affect the public holdings of long-term government debt to a large extent. During OT, the share of long-term over total government securities in the hands of the public did not change by more than 8 percentage points. Although the intervention was only of moderate size, we find a weakly significant compression in the spreads between Treasury yields and the 3-month Treasury bill rate during OT. Alternative securities with similar maturities were, however, not significantly affected by the intervention. The largest policy actions took place a few months after OT was announced, and this timing corresponds to the evidence we find on the effects of OT. We find the largest effects of OT after September 1961.

The remainder of the paper proceeds as follows. Section 2 describes the challenges of monetary policy during the early 1960s and the implementation of OT. Section 3 discusses the theoretical transmission channels. Section 4 explains our estimation method. Section 5 presents the results, and Section 6 concludes.

2 The 1960s – an important phase for U.S. monetary policy

The beginning of the 1960s was an interesting period in U.S. monetary history. Some of today's important U.S. monetary policy concepts date back to that period. For example, the independence of the Fed from the government, quantitative targets for the Fed's actions and the communication thereof to the public were constantly debated during that period (Meltzer, 2010, p. 328-329). After the turbulence of the World War II experience, the Fed was able to establish an environment of price stability during the 1950s. The early 1960s challenged the U.S. monetary policy framework, which obliged the Fed to fulfill the objectives of maintaining price stability and fostering domestic employment under the constraints of the international framework of the Bretton Woods system. The Bretton Woods system was an international agreement on fixed nominal exchange rates in which the U.S. dollar acted as global reserve currency with a fixed convertibility into gold. The Fed had to coordinate its monetary policy actions between domestic obligations and international agreements. This coordination had worked well under a growing economy and ideal international conditions. As a result of World War II the productive capacity of European economies was still limited throughout the 1950s and they had to rely on the U.S. as an important supplier of goods, thereby fostering U.S. exports. The early 1960s challenged the balancing act whereby domestic and international conditions were incorporated into the conduct of monetary policy.

During the 1950s, the balance-of-payment system of the U.S. swung from a surplus to a deficit. A substantial fraction of this decline was due to changes in the relationship between merchandise exports and imports. As Europe began to rebuild its productive capacities and was again able to supply a large number of goods by itself, U.S. exports started to decline. At the same time, U.S. imports were rising, partly due to higher military expenditures abroad but also because of the higher popularity of foreign manufactured goods. Moreover, European interest rates on short-term securities were higher than the rates in the United States. These interest rate differentials led to movements of short-term funds away from the U.S. and towards Europe (see Federal Reserve Bank of St. Louis (1961) for a detailed summary). By the end of the 1950s, the balance-of-payment deficit and the interest rate differentials had led to a strong increase in foreign official dollar holdings. Some of these dollars were converted into gold, leading to substantial gold outflows from the U.S. As these gold outflows accelerated in the early 1960s, pressure on the Fed increased to keep the short-term interest rate above 2 percent, which was, at that time, seen as the critical threshold for preventing further outflows (see Meltzer 2010, p. 308). However, the domestic economy was still weak and just recovering from a recession, and in the eyes of Kennedy's economic advisors, an expansionary monetary policy, i.e. lower interest rates, was needed.

The situation in which interest rates are restricted by a lower bound while the economy is in need of monetary stimulus is, to some extent, comparable to the situation many advanced economies experienced after the Great Recession of 2008-2009. Under such circumstances, a central bank can no longer rely on conventional monetary policy to achieve its policy targets.

In 1961, the Fed had already experienced the limits of conventional monetary policy. The contemporary economic circumstances required the Fed to pursue measures to achieve two goals simultaneously – an expansionary policy aimed at increasing aggregate demand to stimulate the economy out of recession; and a contractionary policy aimed at increasing interest rates to moderate the outflows of capital and, at the same time, reducing aggregate demand (thereby reducing the demand for imports) to dampen the balance-of-payments deficit. Unsurprisingly, the opinions of the members of the Federal Open Market Committee (FOMC) were divided between favoring higher interest rates to ease gold outflows and pushing for lower interest rates to foster domestic employment. The economic advisors of the recently elected Kennedy administration were eager to achieve both targets at the same time and thus proposed a solution that can be seen as an early version of quantitative easing.

A solution called Operation Twist

The goal of OT was to lower long-term interest rates while keeping short-term rates from falling below the desired target of 2 percent. To achieve this goal, the administration of John Kennedy persuaded the chairman of the Fed to cooperate with the Treasury by selling shorter-term securities and using the proceeds to purchase longer-term securities. Purchasing long-term government securities – so ran the idea – would lower long-term interest rates and selling short-term securities would stabilize or even increase, short-term interest rates. Long-term interest rates were considered the dominant factor driving domestic investment, so lowering them would provide additional stimulus for the economy. The implementation and the effects of these actions were heavily debated within the Fed. A substantial fraction of FOMC members did not support the purchase of long-term securities to twist the yield curve. They questioned the effectiveness of such a measure, and they were still in favor of the Fed's "bills-only" policy that had been established in 1953 (Meltzer 2010, p. 323). The "bills-only" policy limited the System's open market operations to Treasury bills.[1] The purpose of this policy was to increase the independence of the Fed from the Treasury by limiting open market operations with long-term government bonds and allowing market forces to determine long-term interest rates. An additional problem originated from the fact that OT was mainly initiated by the economic advisors of the newly elected Kennedy administration, which had harshly criticized the "bills-only" policy during its campaign. Not only was there a large uncertainty about the impact of OT, but the operation would furthermore compromise the Fed's independence, which was seen as a violation of institutional norms. Hence, the FOMC members wanted to be extra careful not to jeopardize the Fed's independence.

2.1 The implementation of Operation Twist

This section offers a detailed account of OT based on official statements and balance sheet data of both the Fed and the Treasury.[2] The goal is to understand exactly what happened during OT, to obtain an idea about the size and actual timing of the actions undertaken by the Fed and the Treasury, and to understand potential problems.

FOMC decisions and official communication

In his first economic message on February 2, 1961, Kennedy asked for lower long-term and higher short-term rates. Although this wording was agreed upon with William Martin - then chairman of the FOMC - the Committee had not yet accepted the policy change (Meltzer 2010, p. 317). At the FOMC meeting on February 7, the policy change was subjected to an intense debate (FOMC Minutes, February 7, 1961).

[1] Under the "bills-only"policy the System had bought coupon issues on only two occasions, once in 1955, when it was deemed necessary to support foundering Treasury financing, and again in 1958, when disorderly market conditions prompted System purchases of coupon issues (Cooper, 1967, p. 5).

[2] Since there was no formal end of OT, we define the OT period as running from February 1961 until December 1963.

In the end, the Committee gave authorization to the Account manager to purchase up to $400 million in securities with maturities beyond fifteen months and up to five and a half years, and an additional $100 million securities with maturities beyond five and a half years and up to ten years (FOMC Minutes, February 7, 1961, p. 50). This decision, however, was not publicly communicated. On February 20, 1961, the Open Market Desk started purchasing longer-term government securities and issued an announcement to the public including the following information: "The System Open Market Account is purchasing in the open market U.S. government notes and bonds of varying maturities, some of which will exceed 5 years" (FOMC Minutes, February 7, 1961, p. 62). In March, the ten-year limitation was removed. In subsequent FOMC meetings, the Committee always renewed the authorization permitting transactions in longer-term securities.

Although the Fed had decided to undertake OT, it remained reluctant to clearly communicate its actions to the public, which left the markets with unclear signals and may have dampened the operation's effectiveness. There was never a formal agreement on whether a reduction in long-term rates was an actual goal of the policy or whether it was just an accepted by-product (Cooper, 1967). This led to considerable confusion on the side of the market regarding the FOMC's objectives with respect to long-term interest rates. The implementation of the Fed's policy actions and, in particular, the management of its asset holdings at this time were in the hands of the managers at the New York Fed. The FOMC's unwillingness to issue specific directives for the managers left them with a substantial degree of discretion (Meltzer 2010, p. 326). The Open Market Desk's intentions were misunderstood and misinterpreted, as the market expected much stronger long-term rate objectives than the FOMC ever wanted to achieve (Cooper, 1967). In a speech on April 11, 1961, Martin noted that the levels of interest rates had been overemphasized, and he made clear that the Fed's objective was mostly to stem the outflow of funds through short-term rates and to facilitate productive investment activities through long-term rates (Cooper, 1967). In December 1961, the FOMC formally discontinued the "bills-only" policy that had been in effect since 1953, making it unnecessary to renew the special authorization at every meeting.

A coordinated action?

Officially, OT was communicated as a coordinated action between the administration, the Treasury and the Fed. However, a careful analysis shows that OT was mostly promoted by the Kennedy administration and that the policy change was highly disputed within the Fed. Tobin (1974, p. 32) even wrote that they were "... forcing Operation Twist ... on the Fed." During the operation, the Council of Economic Advisors accused Martin and the Fed of not having been fully committed to the policy (Meltzer 2010, p. 321). On the other hand, Committee members claimed that the administration hampered the implementation and/or the effects of the operation. For example, FOMC members criticized administration officials for having overstated the intentions of the Fed, thus hampering the effect of the FOMC's policy actions (Meltzer 2010, p. 321).

Moreover, the Fed faced additional obstacles when implementing the policy. In a conversation with Heller and Tobin at the end of May, Martin mentioned problems in the bond market and claimed that the Fed was the "sole" buyer in the market, as the market was convinced that bond yields must rise (Tobin's memo for the record, May 30, 1961). By June 1961, Martin and several FOMC members had lost their conviction that the policy could lower long-term interest rates (Meltzer 2010, p. 321).

Another difficulty was that the Treasury failed to stick to the policy by issuing new five- and six-year notes in March 1961, right after OT was announced, thus increasing the relative supply of long-term securities in public hands and signaling a lack of commitment to the markets. Tobin (1974) criticized the hesitant actions of the Fed and the lack of commitment by the Treasury and claimed that the entire operation had actually never fully been executed. To assess to what extent it was actually implemented, we examine the balance sheets of the two entities.

Operation Twist in numbers

In the literature, the statements regarding the size of OT diverge. Some authors argue that OT was a relatively large program. For example, Swanson (2011) claims that the size of OT was comparable to that of the QE2 program[3], and Zaretsky (1993) notes a dramatic restructuring of the Fed's portfolio during OT. Modigliani and Sutch (1966), on the other hand, claim that OT was a relatively small operation and Meltzer (2010, pp. 323-324) observes that the Fed's portfolio holdings of longer-term government securities changed little during OT.[4] These disagreements might seem surprising at first, but there is a simple reason behind them. While the first authors base their assessment on the Fed's notes and bonds holdings, the latter base their statements on the time to maturity of the government securities holdings in the balance sheet of the Fed.

We take a closer look at the balance sheets of the Fed and Treasury to provide a detailed account of the implementation of OT. In particular, we extract the holdings of government securities by the Fed and the Treasury debt outstanding. For a detailed description of the data see appendix D.
As illustrated above, when the size of OT is assessed, two different measures of long-term and short-term government securities need to be distinguished. We refer to the first measure as *categories*. The categories measure distinguishes Treasury bills, certificates, notes and bonds. The different categories indicate the time to maturity of the security at the date of issuance. Newly issued bills have a maturity of less than one year, certificates mature after exactly one year, notes have a maturity of more than one year and up to five years, and bonds have a maturity over five years. The right-hand panel of Figure 1 shows the composition of the Treasury securities held by the Fed in terms of the different categories. We consider notes and bonds as long-term debt and certificates and bills as short-term debt. This measure does not take into account that the time to maturity of a security changes over time. For

[3]The numbers he uses to compare the size of OT are originally from Meulendyke (1998).
[4]Since there is no official end date of OT, Meltzer uses February 1964, when the Revenue Act of 1964 was signed.

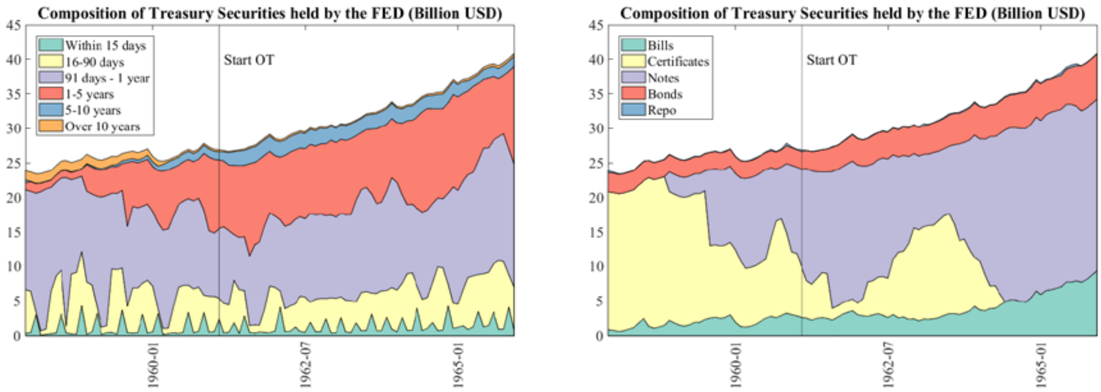

Figure 1: Composition of the Fed's government securities according to their remaining time to maturity (left) and their category (right) for the period December 1957 to December 1965.

example, a 10-year bond that was issued more than nine and a half years ago is still considered a bond, even though it has the same maturity as a freshly issued bill with a maturity of 6 months. A more accurate measure to distinguish long-term and short-term government debt is the *maturity* measure. This measure is based on the remaining time to maturity of a given security. The Fed and the Treasury both publish the maturity structure of the government securities in their respective balance sheets. We apply the maturity classes published by the Fed, which are the following: *within one year, between one and five years, between five and ten years, and over ten years*. We define long-term debt as securities with maturities over one year and short-term debt as securities with maturities of less than one year.[5] The Fed's holdings of Treasury securities in terms of maturities are shown in the left-hand panel of Figure 1.

Comparing the two different compositions of the Fed's balance sheet, the differences are evident. The share of long-term security holdings is somewhat larger in terms of categories than in terms of maturities. These differences have a logical explanation. While an original long-term security remains within the same category over its entire duration period and is thus always considered long-term debt, its time to maturity decreases over time so that it eventually becomes short-term debt according to the maturities measure.

[5]We set the cutoff at one year because no other meaningful distinction between long-term and short-term debt is possible given the available data on the maturities of government securities holdings.

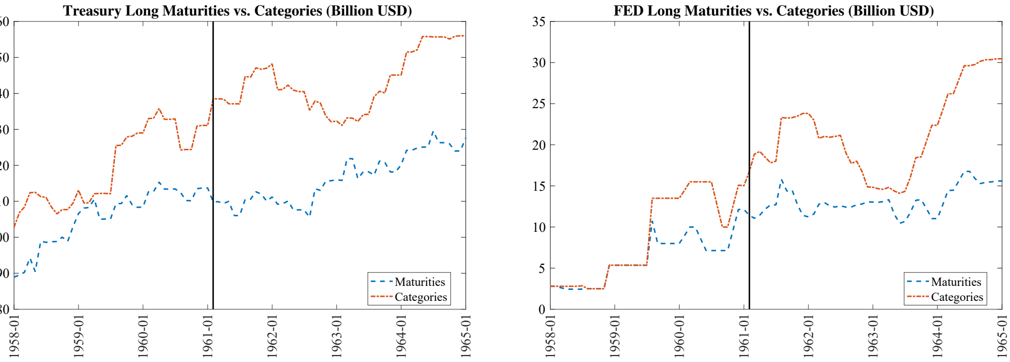

Figure 2: Long-term (maturity > 1 year) Treasury securities outstanding and held by the Fed measured in terms of maturities (blue) and categories (red).

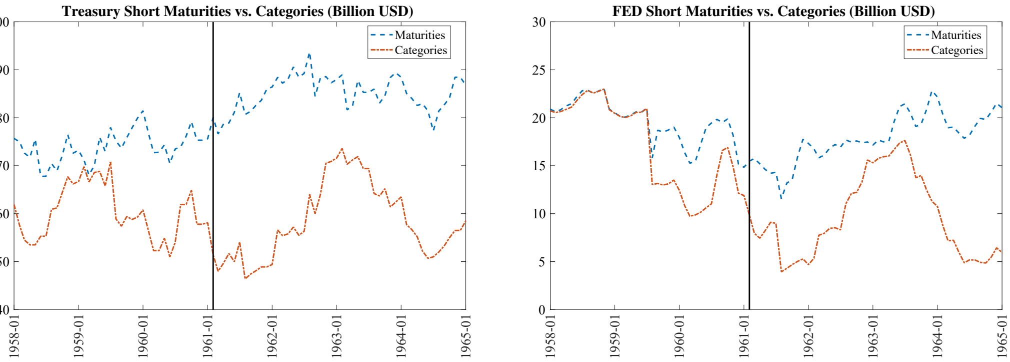

Figure 3: Short-term (maturity ≤1 year) Treasury securities outstanding and held by the Fed measured in terms of maturities (blue) and categories (red).

Figures 2 and 3 show the long-term and short-term Treasury securities in the balance sheets of the Treasury and the Fed. Since the Fed was restricted to only purchasing Treasury bills during the "bills-only" period, the two measures of short- and long-term securities holdings are the same during most of this period. The two measures start diverging in mid-1959, when the Fed exceptionally exchanged short-term for longer-term securities[6] to assist with Treasury refunding. In terms of maturities, Federal Reserve holdings of long-term government securities increase by $4370 million (see the right-hand panel of Figure 2) from the beginning of OT until August 1961. During the same period, the Fed reduced its holdings of short-term government debt by $3924 million (see the right-hand panel of Figure 3). By the end of the year, long-term securities holdings return to their pre-OT level, and short-term securities holdings reach an annual peak. In terms of categories, the Fed increased its long-term government securities holdings between February and December 1961 by $7043 million. During the same period, it reduced its short-term holdings by $4557 million. The purchases of the Fed are much larger measured in categories than in terms of maturities. We have two possible explanations for this: (i) The Fed may have bought notes or bonds that had a maturity of only a few months longer than

[6]More specifically, the Fed exchanged certificates for Treasury notes maturing in 1964 and 1960 (Record of Policy Actions, July 28, 1959). This swap of certificates and notes can be nicely seen in the composition of the Fed's balance sheet in Figure 1.

one year and that would thus turn into short-term securities in terms of maturity only a few months after purchase. The strong decrease in long-term securities holdings measured in maturities during the last quarter of 1961, while the amount of long-term securities measured in categories remained at a high level, points in this direction. (ii) Since, before the implementation of OT, the Fed's government securities purchases were constrained by the "bills-only" policy, the managers might have considered buying notes and bonds of any maturity to be purchasing long-term securities.

To assess what happened in terms of supply, i.e., the overall amount of long-term securities available to the public, we also need to take into account the actions of the Treasury. In terms of maturities, the Treasury reduced the overall amount of long-term debt outstanding from February to July 1961 by $3815 million (see the left-hand panel of Figure 2). However, in March 1961, the Treasury began issuing new securities with maturities between five and ten years to replace maturing bonds, leading to an overall increase in the outstanding amount of this maturity class of $8974 million between February and March. Subsequently, the amount outstanding declines such that by the end of the year, it reaches approximately the same level as in February 1961. In terms of notes and bonds, the Treasury kept the amount of long-term debt roughly constant until August 1961, when long-term debt was subsequently increased until the end of the year. From February 1961 until the end of the year, the Treasury increased the total amount of notes and bonds outstanding by $8500 million. The issuance of short-term debt in the form of bills and certificates increased by $4000 millions until the middle of the year and then decreased by the same amount until the end of the year.

To put these numbers in perspective, Table 1 shows the amount of long-term and short-term securities in the balance sheets of the Fed and the Treasury as shares of total government securities in their respective balance sheets. The shares are annual averages calculated from February of the current year to February of the following year. The Fed increased its share of long-term securities holdings between 1960 and 1961 in terms of both measures. In terms of maturities this increase amounted to 11 percentage points, and in terms of categories, the share of long-term securities increased by 22 percentage points. The Treasury, on the other hand, decreased its long-term debt outstanding only in terms of maturities and this only by three percentage points, whereas in terms of categories, the long-term debt increased by four percentage points. Thus, it seems that between February 1961 and February 1962, the Fed did stick to the plan, whereas the Treasury did not support the operation very consistently.
Eventually, what matters for markets and what determines prices is the overall amount of long-term securities relative to short-term securities available to the public. Only if the supply of long-term government securities relative to short-term securities was reduced, can an effect on long-term yields be expected. If the Fed was just buying long-term securities that were newly issued by the Treasury, this does not affect the relative supply measure since the amount of government securities outside the public sector remains unchanged. Such a neutralization of the two institutions' actions would most likely have had a dampening effect on the desired outcome of

Table 1: Shares of long-term and short-term government securities in the respective balance sheets of the FED and the Treasury (in percent).

Year	FED				Treasury			
	Long		Short		Long		Short	
Feb.-Feb.	*Mat*	*Cat*	*Mat*	*Cat*	*Mat*	*Cat*	*Mat*	*Cat*
1958	13	13	87	87	58	64	42	36
1959	27	38	73	62	59	66	41	34
1960	34	54	66	46	60	70	40	30
1961	45	76	55	24	57	74	43	26
1962	43	63	57	37	56	69	44	31
1963	38	55	62	45	58	68	42	32

OT. Therefore, a powerful measure to assess the joint implementation of OT by the Fed and the Treasury is the maturity structure of the government securities available to the public. This measure shows the net effect of the actions undertaken by both institutions on the composition of government securities held by the public. We compute the relative supply of long-term versus short-term securities as the ratio of long-term government securities in the hands of the public over total government securities held by the public:

$$\frac{\text{Treasury}_{long} - \text{Fed}_{long}}{\text{Treasury}_{short} + \text{Treasury}_{long} - (\text{Fed}_{short} + \text{Fed}_{long})} \tag{1}$$

Figure 4 shows the ratio of long-term securities relative to total government securities in the hands of the public in terms of maturities and categories. The two measures again behave quite differently. In terms of maturities, the relative supply of long-term government securities shows a declining trend starting in mid-1960 and it reaches its lowest point with 57 percent in August 1962. The second half of 1961, however, is a period of increasing supply of long-term securities relative to short-term securities, with the share of long-term securities held by the public reaching 59.5 percent by the end of the year. Based on this measure, we would expect the impact on the markets to be the highest in mid-1961 and mid-1962. Overall, the maturity structure of securities in the hands of the public does not change by much throughout the OT period, with the share ranging between 55 and 63 percent.
In terms of categories, the picture looks quite different. First, in March 1961, the share of long-term securities held by the public reaches a peak of 75 percent. Throughout 1961, the share of long-term securities does not change by much. The lowest amount reached during 1961 is 72.5 percent. During the entire OT period, the lowest share - 67 percent - of long-term securities held by the public was reached in early 1963. Thus, according to this measure we would expect the biggest impact on the yields to happen in early 1963. The evolution of the relative supply in terms of categories was mostly driven by the amount of Treasury notes and bonds outstanding. The relative supply measure quite closely mirrors the development of the Treasury's issues of long-term securities.

While the timing of the joint actions of the Fed and the Treasury varies across the two measures, the overall change in the ratio of longer-term securities held by the public is approximately the same size. According to both measures, the share did not change by more than 8 percentage points during the entire OT period. Whether the formal ending of "bills-only" or the announcement of OT affected market outcomes through a change in expectations remains an open question. Section 3 briefly discusses the potential channels through which OT could have affected yield spreads and the economy.

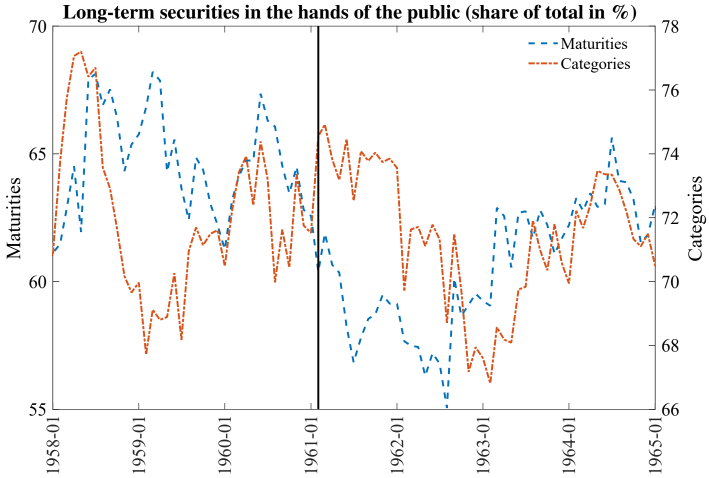

Figure 4: Amount of long-term securities in the hands of the public as share of total government securities in the hands of the public (Left axis: in terms of maturities. Right axis: in terms of categories.).

2.2 Interest rates and yield spreads

Figure 5 shows the evolution during the period around OT of longer-term Treasury rates and private rates and the respective spreads with the 3-month Treasury bill rate. Ten- and 20-year constant maturity rates remain at the same level from the OT announcement through the end of 1965. The same holds for private rates. One- to 5-year rates also remained quite constant until mid-1963, when they started to slightly increase. The 3-month Treasury bill rate remain approximately 2.3 percent until September 1961, when it starts to steadily increase to 4 percent in December 1965. The spreads between the 3-month Treasury bill rate and Treasury rates as well as private rates decline steadily between the last quarter of 1961 and the end of 1965. Increases in the 3-month Treasury bill rate are primarily responsible for closing the gap. The gradual decrease in the yield spreads between 1961 and 1965 might, at first glance, suggest that the policy was successful. As Modigliani and Sutch point out, it is common for the spread to narrow as the economy recovers from a recession.

Taking a closer look at the development around the OT announcement, a slight decrease in the 3- to 20-year Treasury rates can be observed immediately after the OT announcement. However, in mid-1961, the 3- and 5-year rates increase more than their initial decrease. The only time a decrease in the longer term rates can be observed is around the first quarter of 1962. For the spreads, the decline starts towards the end of 1961 and appears to be mostly due to an increasing 3-month Treasury bill rate.

Overall, the longer-term Treasury and private rates remain quite constant throughout the OT period. Changes in the spreads are mostly due to changes in the 3-month Treasury bill rate.

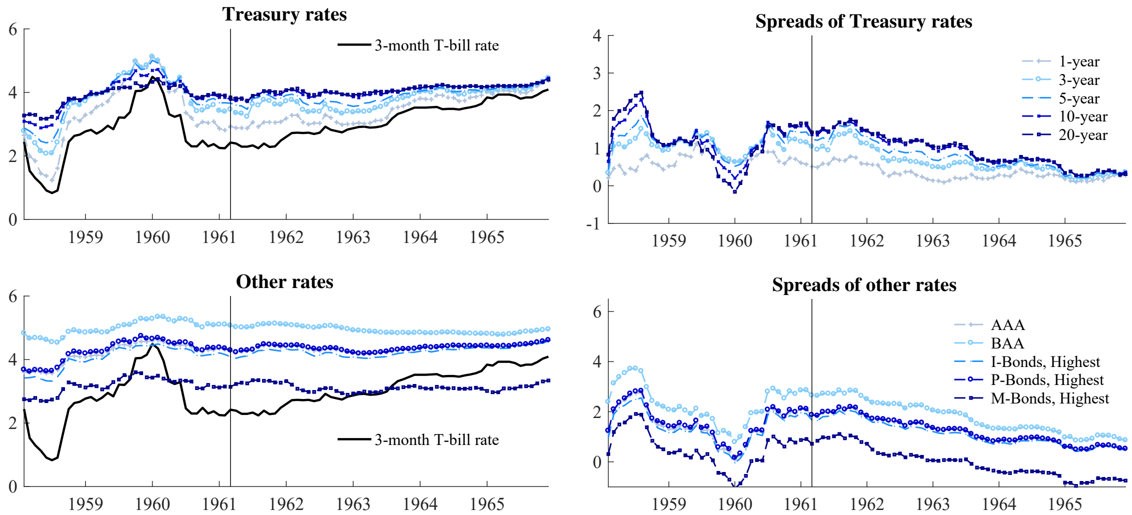

Figure 5: Longer-term interest rates and their spreads with the 3-month Treasury bill rate (AAA and BAA are Moody's Aaa and Baa corporate bond yields, I-Bonds are industrial bonds, P-Bonds are public utility bonds, and M-Bonds are municipal bonds).

2.3 Summing up

Not only was the decade 1960s a seminal period for the framework of U.S. monetary policy during which important characteristics of modern monetary policy were discussed and created. It was also a period in which monetary policy actions were limited by an implicit lower bound on short-term interest rates due to the institutional setting of the Bretton Woods system. To overcome the tradeoff between stopping gold outflows and the need for domestic monetary stimulus, the Fed experimented with a new policy strategy to reduce long-term interest rates without affecting shorter ones. This action, labeled OT led to sharp debates among FOMC members and there is still no broad consensus on its effects.

While in the literature, statements about the size of OT differ when different measures of long-term and short-term securities are used, we assess OT using both measures, and we come to the conclusion that the joint policy actions of the Fed and the Treasury were rather moderate, with the ratio of longer-term to total securities in the hands of the public not changing by more than 8 percentage points during the entire OT period.

3 Theoretical foundation of Operation Twist

Before we turn to an empirical analysis of the OT period in Section 4 we briefly want to discuss the theoretical foundations of such an action and its effects on the economy. Why might swaps of longer-term for shorter-term government securities affect the economy?

In their Jackson Hole conference paper Krishnamurthy and Vissing-Jorgensen (2013) (henceforth KV) provide a detailed overview of the possible channels through which large-scale asset purchase programs (LSAP or QE) by the central bank may affect asset prices and hence asset returns. KV distinguish between QE that purchases mortgage backed securities and QE that focuses exclusively on Treasury bonds. The former was used during the Great Financial Crisis, which originated with U.S. housing markets. Since our analysis focuses on OT, during which the Fed only purchased Treasury securities, we only discuss the latter. The overall effect of QE is often described as a portfolio balance effect. Indeed, that is how such programs mechanically push up asset prices. However, KV argue that this term is too generic to be useful in guiding policy decisions. They then describe more specific and theoretically motivated mechanisms.

Scarcity channels

Safety premium channel

KV also call this channel the asset scarcity channel. This channel is theoretically motivated by preferred habitat models such as those in Modigliani and Sutch (1966, 1967), Vayanos and Vila (2009) and Greenwood and Vayanos (2014). In these models, investors have a special demand for Treasury bonds, which are both safe and liquid. Since there is a limited supply of such safe and liquid assets, the high demand induces a convenience or scarcity premium that increases the price of these assets relative to other assets. When a central bank buys large amounts of such assets, it reduces their supply to the public sector and hence further amplifies their scarcity. This will further inflate their prices. This channel only allows for limited spillover effects. Only assets that fall in the same class as Treasury securities (i.e., safe and liquid) will be affected.

Maturity-specific bond scarcity channel

A very similar but slightly broader channel is the maturity-specific bond scarcity channel. This channel would imply that all assets of similar maturity are affected by purchases of assets of the same maturity. There is vast empirical evidence in favor of the safety premium channel, and our analysis below also leads to the conclusion that OT worked through the narrower channel.

Duration risk premium channel

In comparison to the safety premium channel, the duration risk premium channel is much broader in that it not only affects assets of the type the central bank purchased but also reduces the risk premium in general. In particular, by replacing shorter-term government securities with longer-term government securities in its portfolio, the central bank reduces the relative supply of longer-term securities. A reduction in the net supply of longer-term Treasury securities eases duration risk (less duration risk to hold in the aggregate) for private investors and pushes yields downwards, thus reducing expected returns. The lower expected returns lead investors to purchase other debt securities of similar maturities, such as long-term corporate bonds or equities, encouraging investment in this area and increasing credit flows, improving economic conditions. Evidence in favor of this channel is scarce.

Signaling channel

Asset purchases are often interpreted as signals about the future path of the short-term interest rate. The signaling channel is an additional broader channel through which the central bank can influence economic outcomes by managing expectations about future policy actions. For example, an announcement of an operation such as OT may signal to market participants that the central bank has changed its views on current or future economic conditions, or it may be regarded as a signal about changes in the monetary policy reaction function or policy objectives. Since long-term yields tend to respond more strongly to expectations about future policy actions, managing these expectations is crucial. Krishnamurthy and Vissing-Jorgensen (2011) show that a substantial fraction of the effect of QE1 can be explained through a change in market expectations about path of the fed funds rate. Additionally, Woodford (2012) finds the signaling channel to be important.

4 Methodology

To study whether OT had an effect on the yield curve, we estimate an autoregressive distributed lag (ARDL) model in which we regress the yield spread between bonds of different maturities and the 3-month Treasury bill rate, y_t^i, on lagged values of itself along with a set of explanatory variables, X_t, and lagged values thereof, controlling for the current and past state of the economy. More formally,

$$y_t^i = \beta_0 + \beta_c^x X_t + \sum_{j=1}^{p} \left(\beta_j^y y_{t-j}^i + \beta_j^x X_{t-j} \right) + u_t^i, \tag{2}$$

where u_t^i denotes the reduced-form errors that are assumed to be normally distributed with mean zero.

To capture the effects of OT on the yield spread, we are mainly interested in the residuals of the regression because the operation itself should not be captured by the explanatory variables, and hence, a potential effect should appear in the error term. Under the null hypothesis that OT did not have an impact on the spreads between long- and short-term yields, the residuals are zero-mean. Thus, if OT was successful in compressing the spreads between long- and short-term bond yields, we expect to find a sequence of negative errors during the intervention phase. Such a sequence is difficult to spot when looking directly at the errors, u_t^i. We therefore compute the cumulative sum of errors. If this sum shows a decreasing pattern and does not revert to zero during the OT period, we can interpret this as evidence that OT was indeed successful in compressing yield spreads. To account for uncertainty, we bootstrap the model under the null hypothesis of no anomalous yield spread compression. If the cumulated errors are below the 10th percentile of the bootstrapped cumulative errors, we take this as evidence of a significant yield spread compression.

In the following, we perform a Monte Carlo simulation, and we show that our proposed method is capable of detecting such an anomalous yield spread compression if the size of the shock to the yield spreads and/or its persistence is sufficiently large.

4.1 Monte Carlo simulation

To test the ability of our proposed methodology to detect an anomalous compression of the spread around OT, we perform a small Monte Carlo simulation. The goal of this exercise is to address the following questions:

(1) Assuming that a compression in the spread is sufficiently large, is the proposed methodology capable of detecting it?

(2) Given the historical amount of noise in the data, how large must a spread compression be for the methodology to be able to detect it?

In our simulation, we artificially add a negative shock of size k with persistence ϕ to the yield spread series. We alter the size and persistence of the shock, and we show that if k and/or ϕ are sufficiently large, the model does indeed a perform well in detecting such anomalies.

The data generating process (DGP) consists of a VAR(p) that includes the yield spread[7] along with the following control variables: the civilian unemployment rate, the capacity utilization rate, the vacancy rate, inflation and the 3-month Treasury bill rate (see appendix D for a description of the data). Model 3 describes the DGP in normal times, and model 4 serves as the DGP under OT:

$$\begin{bmatrix} Y_t \\ X_t \end{bmatrix} = B_0 + \sum_{p=1}^{P} B_p \begin{bmatrix} Y_{t-p} \\ X_{t-p} \end{bmatrix} + \begin{bmatrix} \varepsilon_{Y,t} \\ \varepsilon_{X,t} \end{bmatrix} \quad \text{for } t = 1, \ldots, T^S - 1, \tag{3}$$

$$\begin{bmatrix} Y_t \\ X_t \end{bmatrix} = B_0 + \sum_{p=1}^{P} B_p \begin{bmatrix} Y_{t-p} \\ X_{t-p} \end{bmatrix} + \begin{bmatrix} \varepsilon_{Y,t} - \phi^{t-T^S} s(k) \\ \varepsilon_{X,t} \end{bmatrix} \quad \text{for } t \geq T^S, \tag{4}$$

where Y_t is the spread, X_t are the control variables, B denotes the coefficient matrix of the VAR(p), p is the lag order, $\epsilon_t \sim N(0, V)$, and ϕ and k are the persistence and the size of the shock, respectively. We assume that up to period T^S, model 3 is in place. In period T^S, an exogenous shock s of size k and with persistence ϕ hits the economy and compresses the yield spread Y_t. For the moment, $s(k) = k$.
To stay as close as possible to the original problem of detecting the effect of OT on the U.S. economy, we use the exact same sample period as in the original estimation to obtain the estimates of the VAR system matrices that will enter our DGP. For each combination of k and ϕ, we perform 1,000 simulations, and for each simulation, we estimate regression model 2 with 1,000 bootstrap replications each to properly account for uncertainty. The goal is to identify the accuracy with which a shock s

[7] In our simulation, we use the spread between the 10-year Treasury constant maturity rate and the 3-month Treasury bill rate.

can be distinguished from the normal noise that is captured in the error term $\varepsilon_{Y,t}$ for all the different cases. Table 2 reports the half-life of the shock in months for the different degrees of persistence. With $\phi = 0.95$, the shock is still present at half its initial size after one year.

Table 2: Half-life of the shock for different degrees of persistence.

ϕ	*0.5*	*0.8*	*0.95*
Half-life	1m	~3m	~13m

In the following, we summarize the results of our simulation exercise. As a measure of the ability of our method to detect shocks to yield spreads, we take the fraction of cumulative errors that end up below the 10th percentile of the bootstrapped cumulative errors. Figure 6 shows these fractions for different sizes (k) and for different persistence parameters (ϕ) of the shock.
The results of our simulation study suggest that shock s needs to be at least of size $k = 15bp$ ($k = 20bp$) with a persistence of at least $\phi = 0.9$ ($\phi = 0.8$) for our method to detect the shock with at least 90 percent certainty. Larger shocks, e.g., of size $k = 25bp$, are detected in 90 percent of the cases even if they are less persistent. More persistent shocks are detected more easily but in general with some delay. For example, shocks of size $k = 15bp$ and with a persistence of $\phi = 0.95$ are detected in 90 percent of the cases after seven months. However, it proves to be difficult to detect smaller shocks, even when their persistence is relatively high. The reason for this is that the additional exogenous disturbance s has to be distinguishable from the common noise that is present in $\varepsilon_{Y,t}$, so the key issue is the variance of these reduced form errors. With a decreasing variance of $\varepsilon_{Y,t}$, smaller shocks can also be identified.

This exercise shows that our method is able to capture the exogenous shocks to the yield spreads as long as the shocks are of a certain size and persistence. Thus, in theory, this method works well to recover the potential yield spread compression caused by OT. In practice, however, the situation is possibly more complicated than in a simulated environment in which we are able to control for all eventualities. The series entering the model and the potential shocks affecting the spread are probably not as well behaved, thus complicating the detection of the actual shock. Moreover, the economy might be simultaneously hit by other exogenous shocks, and our method is not able to distinguish these different exogenous shocks.

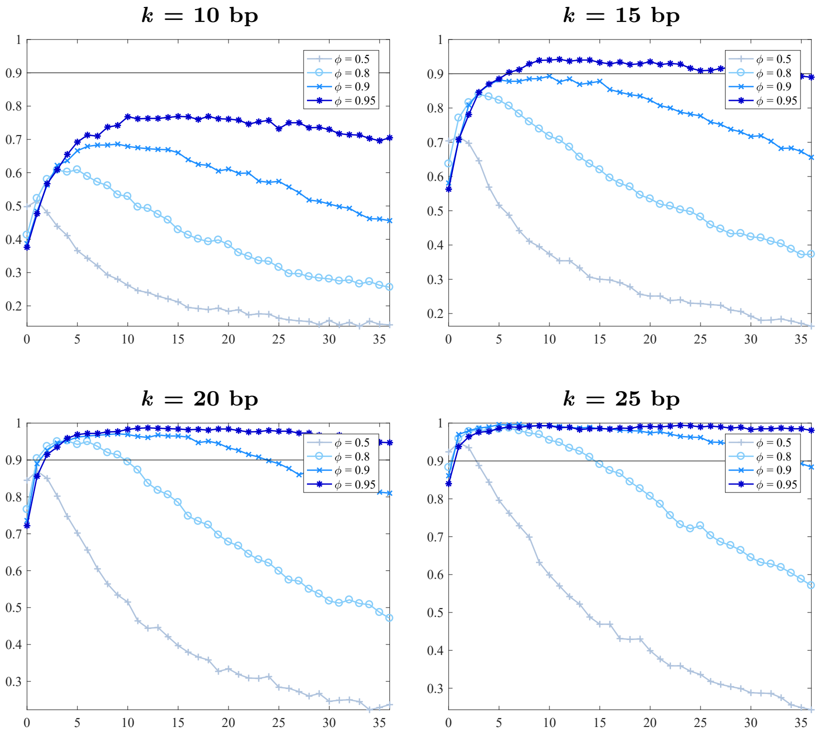

Figure 6: Fraction of cumulative errors that fall below the 10th percentile of the bootstrapped cumulative errors for shocks of size k and with persistence ϕ.

5 Estimated effects on the yield spreads

We use monthly data for the period from October 1955 to December 1965 to estimate the ARDL model we described in Section 4.[8] In particular, we estimate the model for the spreads of five Treasury constant maturity rates, several private and other bond rates using the civilian unemployment rate, the capacity utilization rate, the vacancy rate, inflation, real stock returns and the 3-month Treasury bill rate as control variables. The choice of these specific variables is due to economic reasoning and the availability of unrevised series for the period of interest.[9] Figure C.1 in the appendix shows the control variables. A detailed description of the data can be found in Appendix D.

The number of lags, p, included in each regression is chosen as the maximum between the Akaike, Schwarz, and Hannan-Quinn information criteria, where the minimum lag length is set to $p = 3$ and the maximum lag length is set to $p = 12$. Table 3 reports the variance of the residuals, the R^2 and the adjusted R^2 of the estimated regressions. The variance of the residuals is highest for the 1-year Treasury rate and decreases for longer maturities. The R^2 measures the proportion of variation in the

[8]Ideally, we would want to take a longer sample for our estimation; however, the breakdown of the Bretton Woods system increased the volatility in the series. Extending our sample would increase the variance in our model and thus make it harder to detect small shocks.

[9]Due to fears of collinearity, we also estimated a smaller model that includes only the unemployment rate and discards the capacity utilization and the vacancy rate. Qualitatively, the results are the same, and the quantitative differences are small.

Table 3: Variance of the residuals and R^2 for different spreads.

Spreads of	Variance of u	R^2	10-90 perct.	adj. R^2	10-90 perct.
1-year	0.0094	0.845	[0.754;0.920]	0.798	[0.679;0.896]
3-year	0.0087	0.934	[0.907;0.976]	0.914	[0.879;0.968]
5-year	0.0075	0.958	[0.949;0.986]	0.945	[0.933;0.982]
10-year	0.0046	0.981	[0.980;0.995]	0.975	[0.974;0.993]
20-year	0.0024	0.992	[0.992;0.998]	0.990	[0.990;0.997]
AAA	0.0015	0.996	[0.995;0.999]	0.995	[0.993;0.998]
BAA	0.0011	0.998	[0.997;0.999]	0.997	[0.996;0.999]
I-Bonds, Highest	0.0031	0.991	[0.988;0.997]	0.988	[0.985;0.996]
I-Bonds, Lowest	0.0013	0.997	[0.996;0.999]	0.996	[0.994;0.998]
I-Bonds (High Grade)	0.0030	0.991	[0.989;0.997]	0.989	[0.986;0.996]
Fed. Housing Mortgages	0.0005	0.999	[0.999;1.000]	0.999	[0.999;1.000]
P-Bonds, Highest	0.0018	0.995	[0.994;0.999]	0.994	[0.993;0.998]
P-Bonds, Lowest	0.0026	0.994	[0.992;0.998]	0.992	[0.990;0.997]
M-Bonds (High Grade)	0.0054	0.990	[0.988;0.997]	0.987	[0.984;0.996]
M-Bonds, Highest	0.0044	0.990	[0.988;0.997]	0.986	[0.984;0.996]
M-Bonds, Lowest	0.0046	0.993	[0.991;0.998]	0.990	[0.989;0.997]
M-Bonds, 20 Bond Av.	0.0055	0.988	[0.987;0.997]	0.985	[0.982;0.995]

Note: I-Bonds denote industrial bonds, P-Bonds denote public utility bonds, and M-Bonds denote municipal bonds.

dependent variable that is explained by the regressors. The adjusted R^2 adjusts for the number of regressors in the model relative to the number of data points. In all cases, the R^2 is higher than 0.8, and for most of the yield spreads, it is very close to 1. These are standard numbers in such types of models and suggest that the model is able to explain a substantial fraction of the variation in the yield spreads.

Figure 7 shows, for each of the spreads, the regression residuals (left column), their 12-month rolling average (middle column) and the cumulative sum of the residuals starting in February 1961 (right column), together with the respective 10- and 90-percent and 16- and 84- percent bootstrapped confidence bands. Significant outliers in the monthly errors around the OT announcemnt dates give a first hint for an anomalous compression in the spreads. For the spreads of the 3- to 20-year Treasury rates, there indeed is a sequence of negative errors after the announcement of OT. However, we also observe some positive errors. The cumulative sum of the monthly errors is a more informative measure, as it visually shows the divergence of the cumulative sum away from zero. For the spreads of the 3-, 5-, 10- and 20-year Treasury constant maturity rates, the cumulative residuals immediately drop below the 10-percent confidence bands. The cumulative errors remain significantly negative until May, when a series of positive shocks drives them up again. For the spreads of the 1- to 5-year Treasury rates, the cumulative sum even becomes positive for a few months, although not significantly so. Starting in September, the cumulative errors begin to decrease again for the spreads of all Treasury rates. By the first quarter of 1962, for most Treasury rates, the cumulative errors reach negative values below their respective 10-percent confidence bands. Overall, the residuals clearly tend to be one-sided after the OT announcement, with the exception of the third quarter of 1961, during which a sequence of positive errors inflates the yield spreads. The 12-month rolling averages of the monthly errors show the same tendency. In our eyes, this is evidence for OT having the desired impact on the spreads of Treasury yields. In terms of timing there seems to be a slight delay until the impact on the yield curve becomes visible for all spreads. This is in line with the simulation results in Section 4.1. They suggest that the more persistent the shock is, the longer it takes until the cumulative errors fall below the 10-percent confidence band. This holds for a substantial fraction of simulations.

The overall pattern of the cumulative errors for the other yield spreads quite closely resembles those of the 1- to 5-year Treasury rates. For some bond rates, the cumulative errors become significantly positive during the third quarter of 1961. These are the rates of the Baa rated corporate bonds, the lowest rated industrial and public utility bonds (I-Bonds and P-Bonds, respectively), and the highest rated municipal bonds (M-Bonds). For these rates the cumulative errors also do not become significantly negative during the entire OT period. The only rates other than Treasury rates for which the cumulative errors become significantly negative during the OT period are those of Aaa rated corporate bonds and high grade municipal bonds. These results indicate that the OT intervention was not able to significantly affect yield spreads other than those of Treasury bonds.
The theoretical channels through which central bank long-run asset purchases could affect yield spreads might provide a possible interpretation of our findings. The series of negative errors observed for the spreads of 3- to 20-year Treasury rates immediately after the OT announcement might have been caused by a signaling effect of the announcement. By announcing the purchases of long-term government securities, the Fed signaled to the market participants that it would pursue the policy proposed by Kennedy of lowering long-term interest rates, abandoning the "bills-only" policy. This announced change in monetary policy might have lowered the expectations component of long-term rates, leading to lower long-term yields. During the following months, the markets might have expected stronger policy actions than the Fed actually pursued (see Section 2.1), which could be an explanation for the series of positive residuals from June to August. In September, approximately one month after the joint actions of the Fed and the Treasury reduced the relative supply of longer-term government securities – measured in terms of maturities – to its smallest amount during 1961, the cumulative residuals exhibit a steep drop. This evidence points towards a delayed portfolio rebalancing effect. By reducing the net supply of long-term government securities, the Treasury and the Fed reduced the spreads between long-term assets and the 3-month Treasury bill rate. The fact that we do not find a significant compression of the spreads among all maturities, especially for private sector assets, suggests that the safety premium channel is the dominant channel here.

5.1 Potential size of the shock

The above analysis shows a mild success of OT in compressing the yield spreads of longer-term Treasury securities. In a next step, we try to quantify how large these effects were and how long they lasted. For this purpose, we take the cumulative errors from our estimations, and we try to find the closest match to a simulated cumulative error series produced by the simulation model described in Section 4.1, using a grid search for the parameters k and ϕ. More specifically, we perform a grid search for k and ϕ in which we minimize the sum of the squared distance between the actual cumulative errors and the median of 1,000 simulated cumulative errors

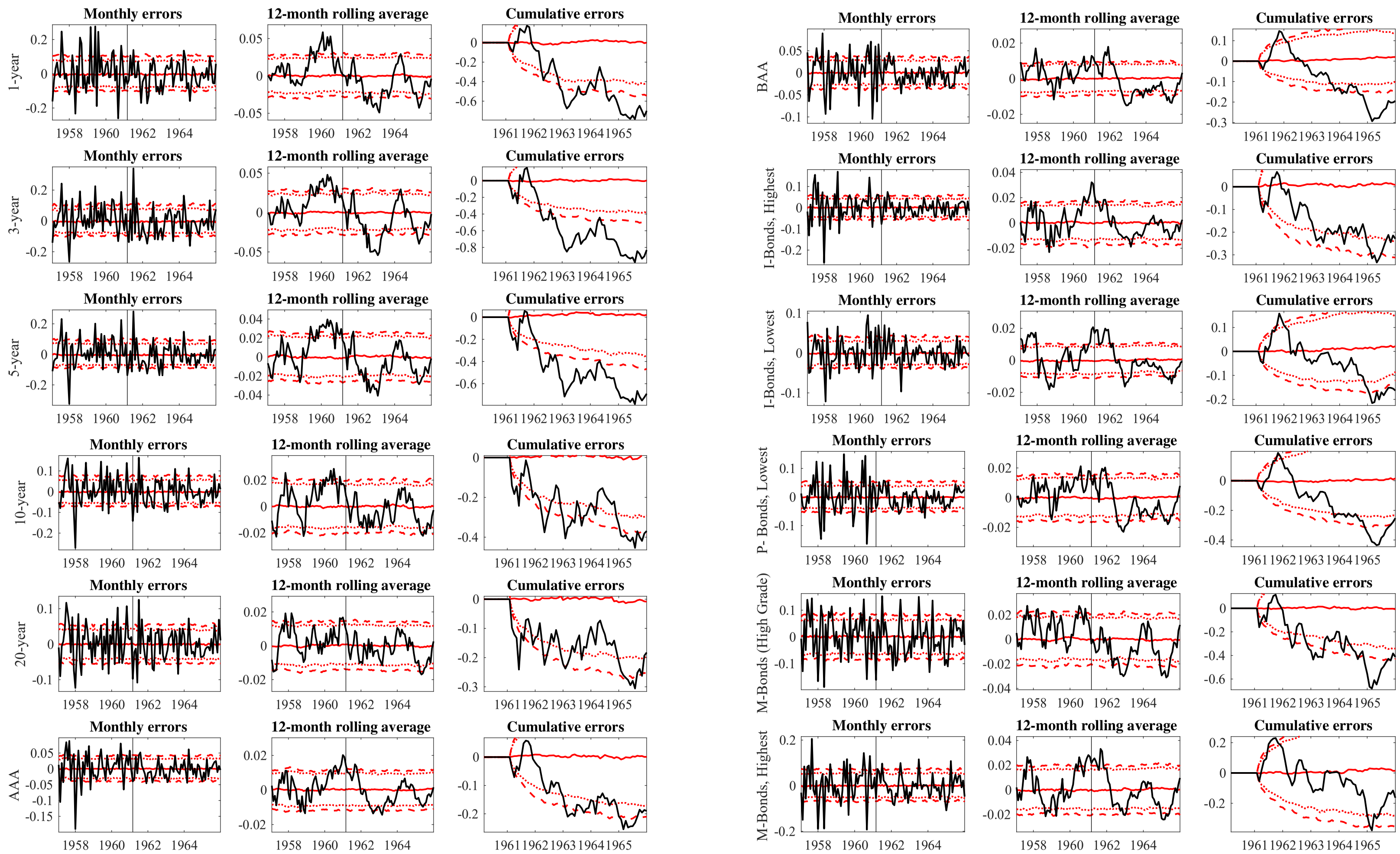

Figure 7: Monthly errors, 12-month rolling averages, and cumulative errors of the ARDL regressions along with the medians (red, solid), the 10th and 90th percentiles (red, dashed) and the 16th and 84th percentiles (red, dotted) bootstrapped under the null.

for every k - ϕ pair. We are well aware that the simplistic way we model the OT shock is most likely not able to capture reality one for one, but we still might obtain an approximation of the shock size. With this specification of the model, we assign the effect to a single initial shock with a certain persistence. Of course, one could obtain a similar result by assuming a sequence of nonpersistent shocks. However, we think that the former is consistent with the fact that most of the action took place in February 1961, and the latter shocks identified in Swanson (2011) in March 1961 and April 1961 most likely offset each other as they affected yields in different directions. Figure 8 shows the results of the grid search for the 1-, 3-, and 5-year Treasury yield spreads. In particular, on the left-hand side, we show the heat maps for the k and ϕ combinations, where white areas indicate a close match and black areas indicate a large distance from the estimated pattern. The distance criterion we applied here is simply the sum of the squared distances. On the right-hand side, we show the actual cumulative errors (in blue) together with the medians (in black) and the 10-90 confidence bands of the closest match of the simulated cumulative errors (in red). In all three cases, the closest matches are produced by a rather small shock ($k = 8$ or 10 bp) with a very high degree of persistence ($\phi = 0.99$ in all three cases). For the spreads of the 1-year and 3-year Treasury rates, the actual cumulative errors exceed the 90-percent confidence bands between June and August when a series of positive shocks hit the spread series.

To avoid the series of positive shocks between June and August 1961 distorting the search for a matching k - ϕ pair (as we are clearly unable to match such a pattern with our formulation of the shock), we also perform a grid search in which we start summing the errors in September 1961, when the downward trend in the cumulative errors is the steepest. Figure 9 shows the results of the grid search for the cumulative errors starting in September 1961. The median cumulative errors that are the closest match to the actual cumulative errors are now caused by larger ($k = 14$ or 16 bp), but still very persistent ($\phi = 0.95$, 0.97, 0.99) shocks.

For the spreads of the 10- and 20-year Treasury rates, the grid search produces results that do not narrow down the k - ϕ combinations very well. Figures C.2 and C.3 in the appendix show the results for these two Treasury rates. The heat map suggests that there are many k - ϕ combinations that would produce cumulative errors that are a close match to the actual cumulative errors.

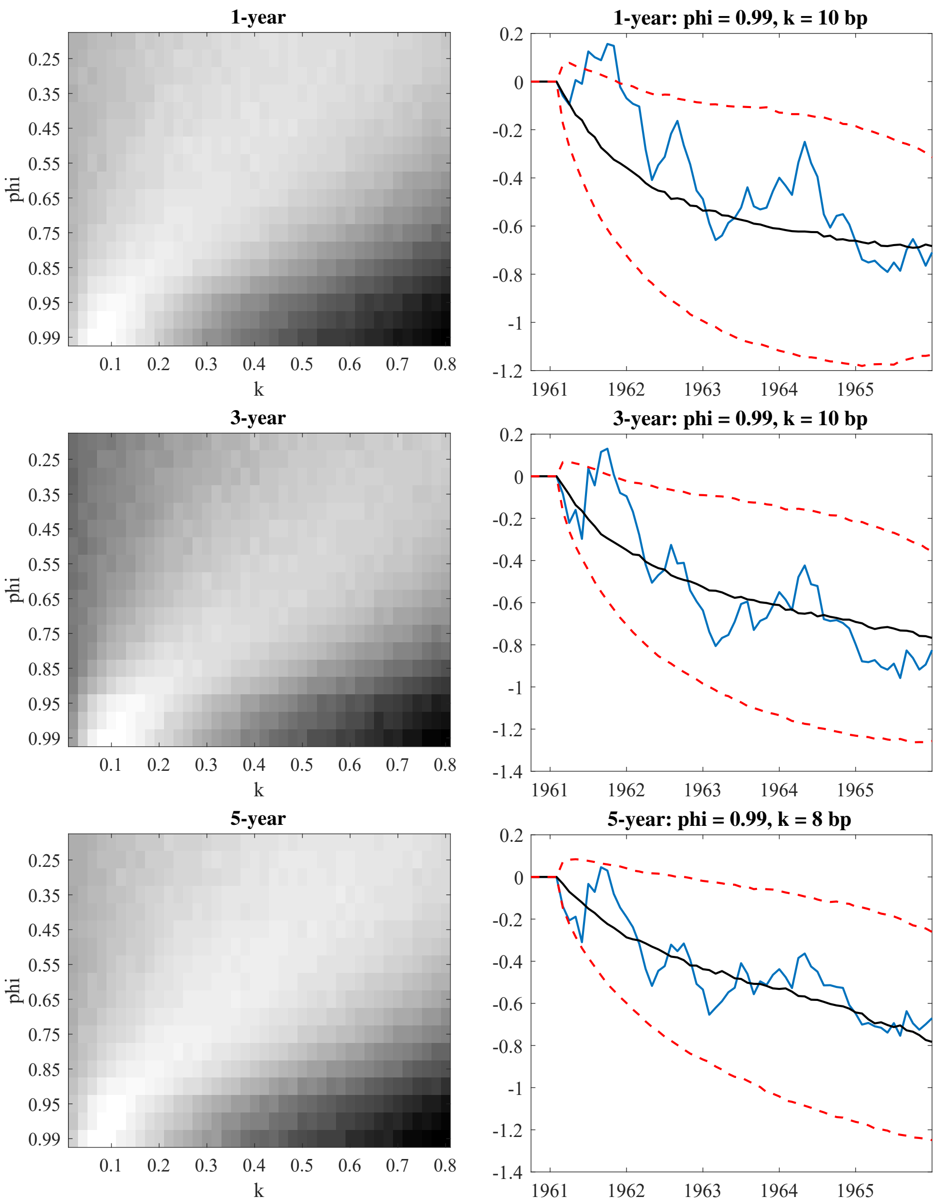

Figure 8: Grid search results (cumulation starts in February 1961): heat map in which white areas indicate a close match (left panel) and cumulative errors of the original ARDL regression (in blue) together with the median (in black) and the 10th and 90th percentiles (in red) of their closest match (right panel).

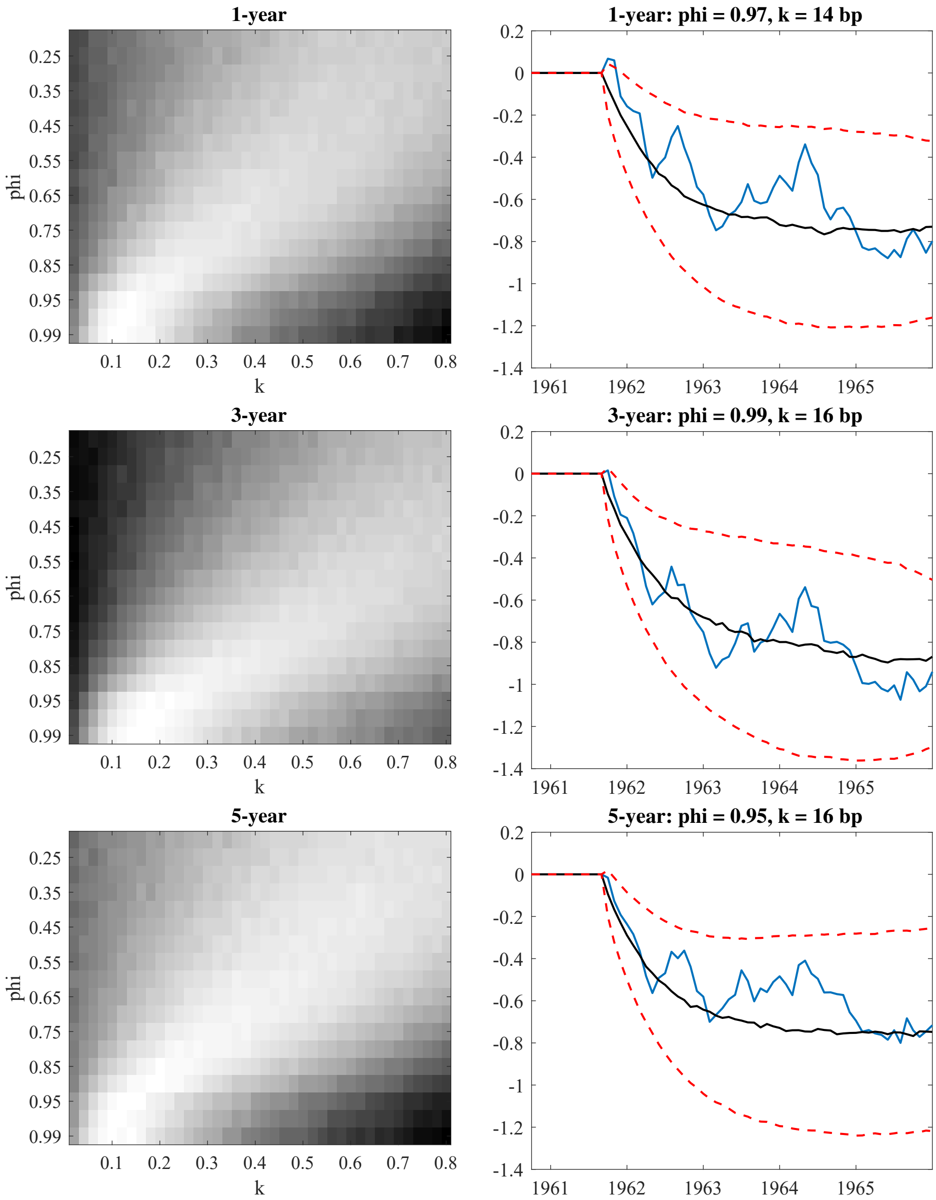

Figure 9: Grid search results (cumulation starts in September 1961): heat map in which white areas indicate a close match (left panel) and cumulative errors of the original ARDL regression (in blue) together with the median (in black) and the 10th and 90th percentiles (in red) of their closest match (right panel).

These findings suggest that the initial effect of OT on the yield spreads lies in the area of -10 bp to -15 bp, with a relatively high persistence. This result is closely in line with conclusions 3. and 4. documented in Modigliani and Sutch (1967). They find a compression of the spread of approximately 12 bp, however, they argue that it is largely attributable to the successive increase in the ceiling rate under Regulation Q. They further predicted that "any effects, direct or indirect, of Operation Twist in narrowing the spread which further study might establish, are most unlikely to exceed some ten to twenty base points a reduction that can be considered moderate at best."(Modigliani and Sutch, 1967, p.196) Moreover, our finding is also in line with the estimated effect of OT of -15 bp in Swanson (2011), who finds an effect of similar magnitude for QE2.

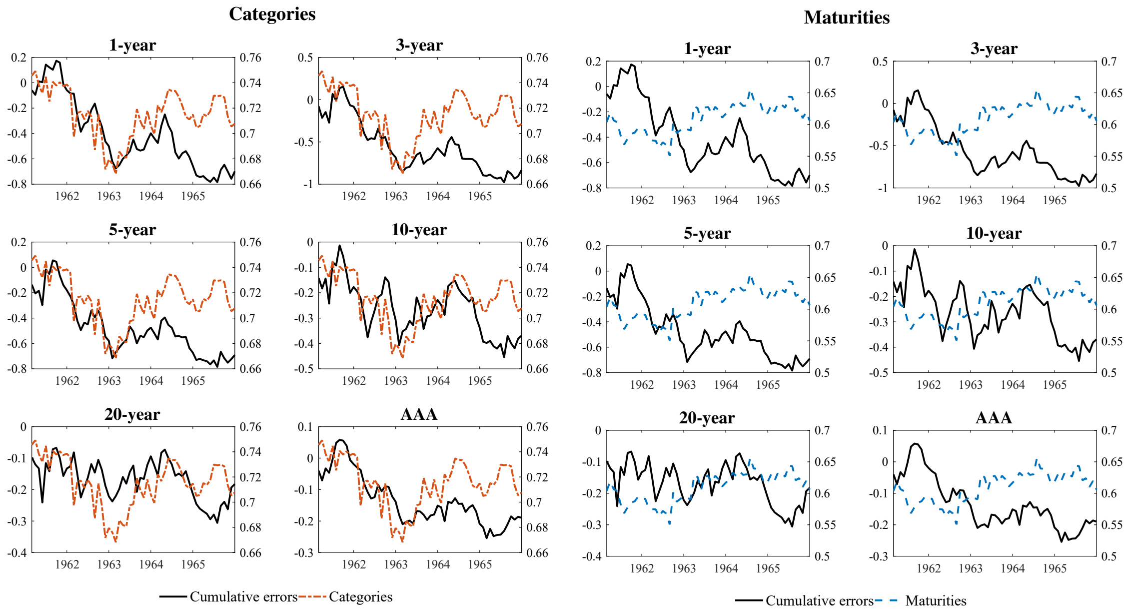

Figure 10: Cumulative errors (in black) along with the share of long-term over total government securities in the hands of the public in terms of maturities (in blue) and categories (in red).

5.2 Relative supply of long-term versus short-term securities

In a next step, we assess whether a relationship between the cumulative errors and the joint policy actions of the Fed and the Treasury exists. Figure 10 shows, for the Treasury rates and the AAA rate, the cumulative errors from the above estimation together with the share of long-term over total government securities held by the public in terms of categories (red) and maturities (blue). While for the maturities measure no clear relationship with the cumulative errors is established, there seems to be quite a strong comovement between the categories measure and the cumulative errors.

We indeed find a strong positive contemporaneous correlation between the share of long-term securities measured in categories and the cumulative errors for the spreads of the 1-, 3-, and 5-year Treasury rates during the OT period[10] (see Figure 11). A decrease in the relative supply of long-term securities is thus accompanied by a decrease in the yield spreads of the 1- to 5-year Treasury securities during the OT period. In the period afterwards, this close relationship disappears. This evidence suggests that the policy actions together with the announcements of OT relate to the anomalous behavior of the Treasury yield spreads during that period. If the relative supply of Treasury notes and bonds decreases, the Treasury yield spreads tend to be lower than predicted given the state of the economy. The correlation with the cumulative errors for the spreads of the 10- and 20-year Treasury rates is less strong but is still at least 0.5. The positive correlation vanishes if we measure the relative supply of long-term government securities based on the maturity definition. This finding is somewhat puzzling since we would have expected the yields to mostly

[10]We define the OT period as going from February 1961 to December 1963.

react to the maturity composition of the securities available. However, the strong correlation with the categories measure suggests that the amount of notes and bonds available to the public are crucial for changes in yield spreads. A reason why the categories of government securities matter more than their maturities might be that because of the "bills-only" policy that was in place before OT, the markets and the Open Market Desk that executed the purchases for the Fed both thought in terms of categories and not in terms of the effective maturities in their portfolios. If the Fed was buying bonds of any maturity, this might have signaled a policy change to the markets, and thus prices may have reacted despite the maturity of these bonds potentially being the same as that of a Treasury bill.

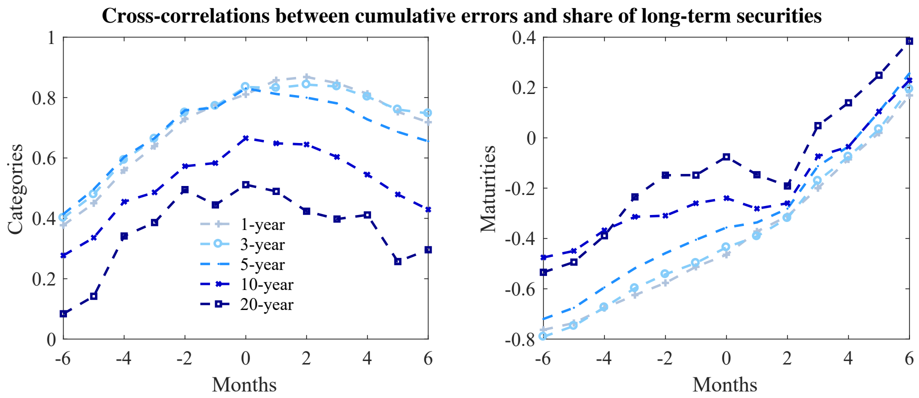

Figure 11: Correlation between cumulative errors and relative supply measures during the OT period (February 1961 - December 1963) for the category (left panel) and maturity definition (right panel).

5.3 Robustness

We first test the robustness of our results with respect to changes in the model specifications. In particular, we estimate the ARDL model using a longer sample period, changing the set of control variables, and choosing yields instead of spreads as the dependent variable. In a second step, we repeat our analysis using two extended models. The model we introduced in Section 4 is appealing because of its simplicity. However, the question arises whether it might be too simple to capture all the empirical occurrences. To check for robustness against possible misspecification problems, we repeat our analysis with a model that allows for stochastic volatility (SV), which can handle changes in the volatilities of the error terms and a time-varying parameter (TVP) model, which can handle additional non-linearities such as breaks in the mean of the spread series. To obtain better estimates, we increase the sample size when estimating the two models below. The results clearly suggest that volatility changes over the sample period, which is ignored by the linear model of Section 4. Furthermore, the results from the TVP model also indicate that the mean of the different spread series is not constant but displays certain changes over time. However, our general finding that OT did compress the yield spreads of, at least, the Treasury rates is robust to the different model specifications and the application of more sophisticated models.

5.3.1 Changing model specifications

All results of our robustness analysis are reported in the appendix. We first verify the robustness of our results with respect to a longer sample period. Specifically, we extend the sample period to December 1967. As expected, the variance of the residuals is higher than in the benchmark sample. Other than that, the results are very similar to those in the benchmark specification. The biggest differences arise for the spreads of the AAA and BAA rates, as well as for those of the industrial bonds (I-Bonds).[11] When we use the longer sample period, the cumulative errors also fall below the 10th percentiles of the bootstrapped cumulative errors for those interest rates. The longer sample period also leads to a higher correlation between the relative supply and the cumulative errors of the 10- and 20-year Treasury rates. We also performed a grid search for the parameters using the longer sample and the resulting parameters are very close to the onesthose of the benchmark sample. Furthermore, we include different sets of control variables. As a first set of different controls, we take inflation, unemployment and the 3-month Treasury bill rate. Leaving out some of the control variables increases uncertainty but not much else changes. A more interesting case is when we omit the 3-month Treasury bill rate from the control variables. We then observe an even larger increase in uncertainty around the cumulative errors. However, more interestingly, for the 10- and 20-year Treasury rates and the AAA and BAA corporate bond and industrial bond yields the cumulative errors exhibit, after an initial drop in February 1961, a positive trend until mid-1963. Not controlling for the movements in the 3-month Treasury bill rate thus leads the model to underestimate the yield spreads during OT. We take this as evidence for including the 3-month Treasury bill rate into our regression model. Finally, we estimate the model for the longer term rates instead of the spreads. The results are strikingly similar to those in our benchmark regression.

5.3.2 A model with stochastic volatility

As we have already mentioned above, a crucial parameter for the success of our method to detect the effectiveness of OT is the variance of the model's error terms. If the variance displays certain breaks over our period of interest, this might possibly affect the outcome. To address the question of how the volatility of the residuals, u_t, behaves over time and whether this behavior has an influence on the results shown above, we reestimate model (2) relaxing the assumption of constant variances and allow for stochastic volatility of the error terms, u_t^i, instead. For this purpose we extend the model as follows: The reduced form errors, u_t, are assumed to be normally distributed with time varying variance, e^{h_t}, where h_t denotes the unobserved log volatilities that evolve according to an autoregressive process of order one. The initial condition, h_0, is drawn from the stationary distribution of this autoregressive process. More details on the model estimation can be found in Appendix A.1.

Figure A.2 shows the cumulative errors from the SV model for the four Treasury spreads, as well as the AAA and BAA spreads. The picture is very similar to that of the simple model. For the spreads of public bonds the cumulative errors show a clear

[11] The other rates are not available for the longer sample period.

downward tendency in the aftermath of OT, while the results for the two private bonds again look quite different.

5.3.3 A model with time varying parameters

While there is vast evidence for time varying volatility in the data, the model with stochastic volatility presented above cannot account for possible changes or breaks in the other parameters of the model. To control for such effects, we introduce an additional version of the model where, along with the variance of the errors, the regression coefficients are allowed to vary over time. To economize on the scale of the state space system we use a model where the parameters possess a factor structure. We estimate the model using Bayesian MCMC techniques and assume independent priors for the model parameters. More details on the model estimation can be found in Appendix A.2.

The cumulative errors of the TVP model shown in Figure A.3 do look different than those of the previous two models, but they seem to support the evidence of a negative effect of OT on the yield spread for U.S. Treasury securities.

6 Conclusion

We study the implementation and success of the first version of quantitative easing in the history of monetary policy. The origin of unconventional monetary policy tools dates back to an intervention by the U.S. Federal Reserve System under the Kennedy administration in 1961, today known as Operation Twist. The economic situation of the early 1960s, in which the Fed was facing a trade-off between different policy targets, led to this unconventional intervention. On the one hand, the Fed wanted to stop gold outflows towards Europe, which were mainly caused by the institutional setting of the Bretton Woods system, and on the other hand, it wanted to deliver monetary stimulus for the domestic economy. To achieve both targets simultaneously, the Kennedy administration convinced the Fed to cooperate with the Treasury to provide monetary stimulus for the economy by lowering long-term interest rates while simultaneously putting upward pressure on short-term interest rates. This maneuver attempted to lower the relative supply of long-term Treasury securities available to the public.

We study the impact of OT on the spreads between long- and short-term securities using a novel approach based on state-of-the art time series techniques. In a simulation study, we demonstrate the power of our methodology. We find evidence that OT did indeed succeed in lowering the spreads between long-term and short-term interest rates for the corresponding Treasury securities, while it did not have a significant dampening effect on alternative securities with similar maturities. To better put our results into the historical context of the whole operation, we collect balance sheet data covering the holdings of Treasury securities of various maturities by the Fed, as well as the total amount of outstanding government securities in the books of the Treasury. These data suggest that OT was of moderate size and that the often drawn picture of a perfectly coordinated action cannot be supported. The Fed acted only with a delay to its announcement of OT, and the Treasury lacked full commitment, as it continued to issue long-term securities during the intervention period. These historical facts are absolutely in line with our empirical findings. They point out that OT succeeded in narrowing the spreads; however, the operation's effect on the yield curve of government securities was rather modest in size, and we do not find a significant compression in the yield spreads of other bonds with similar maturities. Whether a larger, better coordinated, and stronger supported effort could have had a larger effect remains an open question but seems to be plausible. Therefore, coming back to the initial question – shall we twist? – we reply Yes, but do so with passion!

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A Alternative models

The model we introduced in Section 4 is appealing because of its simplicity. However, the question of whether it might be too simple to capture all the empirical occurrences arises. To check for robustness against possible misspecification problems, we repeat our analysis with an extended model that can handle changes in the volatilities and an even richer model that can handle additional nonlinearities. To obtain consistent estimates, we increase the sample size when estimating the two models below. The results clearly suggest that the volatility changes over the sample period, which is ignored by the linear model of Section 4. Furthermore, the results from the TVP model indicate that the mean of the different spread series also is not constant.

A.1 A model with stochastic volatility

To address the question of how the volatility of the residuals, u_t, behaves over time and whether this behavior has an influence on the results shown above, we reestimate model (2) relaxing the assumption of constant variances and allowing for stochastic volatility for the error terms, u_t^i, instead. For this purpose, we extend the model as follows: The reduced form errors, u_t, are assumed to be normally distributed with time varying variance e^{h_t}, where h_t denotes the unobserved log volatilities that evolve according to an autoregressive process of order one. The initial condition, h_0, is drawn from the stationary distribution of this autoregressive process.

$$y_t^i = \beta_0 + \beta_c^x X_t + \sum_{j=1}^{p} \left(\beta_j^x X_{t-j}\right) + u_t^i \tag{5}$$

$$u_t^i | h_t \sim N\left(0, e^{h_t}\right) \tag{6}$$

$$h_t | h_{t-1}, \mu, \phi, \sigma_\eta \sim N\left(\mu + \phi(h_{t-1} - \mu), \sigma_\eta\right) \tag{7}$$

$$h_0 | \mu, \phi, \sigma_\eta \sim N\left(\mu, \sigma_\eta^2/(1-\phi^2)\right) \tag{8}$$

We estimate the model using Bayesian MCMC techniques and assume independent priors for the model parameters. The prior for the regression parameters is normal $\beta \sim N\left(b_\beta, B_\beta\right)$, while following Kastner and Frühwirth-Schnatter (2014), the priors for the remaining parameters are given by

$$\mu \sim N\left(b_\mu, B_\mu\right) \tag{9}$$

$$(\phi + 1)/2 \sim \mathcal{B}\left(a_0, b_0\right) \tag{10}$$

$$\sigma_\eta^2 \sim \mathcal{G}\left(1/2, 1/2B_{\sigma_\eta}\right) \tag{11}$$

The conditional posterior distribution of the regression parameters is normal $\beta|\cdot \sim N(\bar{b}_\beta, \bar{B}_\beta)$ with

$$\bar{B}_\beta = \left[\sum_{t=p+1}^{T} \sigma_t^{-2} X_t X_t' + B_\beta^{-1}\right]^{-1} \tag{12}$$

$$\bar{b}_\beta = \bar{B}_\beta \left[\sum_{t=p+1}^{T} \sigma_t^{-2} X_t X_t' + B_\beta^{-1} b_\beta\right] \tag{13}$$

To compute the posterior of the log-volatilities, we apply the algorithm described in Kastner and Frühwirth-Schnatter (2014), which is implemented in the stochvol package for R; see Kastner (2016) for a detailed description. The prior values for the regression coefficients, b_β, are set to the OLS estimates for β, and the variance, B_β, is set relatively large, such that the prior is rather uninformative. The mean and the variance for the prior of the level of the log-variance are set to $b_\mu = -10$ and $B_\mu = 4$, respectively, while the hyperparameters for the persistence of the autoregressive process are set to $a_0 = 1.5$ and $b_0 = 20$, as in Kim et al. (1998). B_{σ_η} is set equal to 1 but as mentioned in Kastner (2016), the choice of this hyperparameter is not influential as long as it is not set to very small numbers.
Figure A.1 contains the estimated variances for the errors of the regression models, including the Treasury spreads, as well as the spread between Moody's AAA and BAA and the 3-month Treasury bill rate. There is indeed vast evidence against a constant variance, as the estimated volatilities for all the different spreads show a substantial degree of time variation. The pattern is quite similar in all six cases. After the recession that ended in 1961, there is a substantial drop in the variances of the errors and they remain at a historically low level for that time until approximately 1967, when the Bretton Woods system started to show the first cracks. Figure A.2 contains the cumulative errors from the SV model for the six spreads. The picture is very similar to that of the simple model; for the spreads of the public bonds, the cumulative errors show a clear downward tendency in the aftermath of OT, while the results for the two private bonds again look quite different.

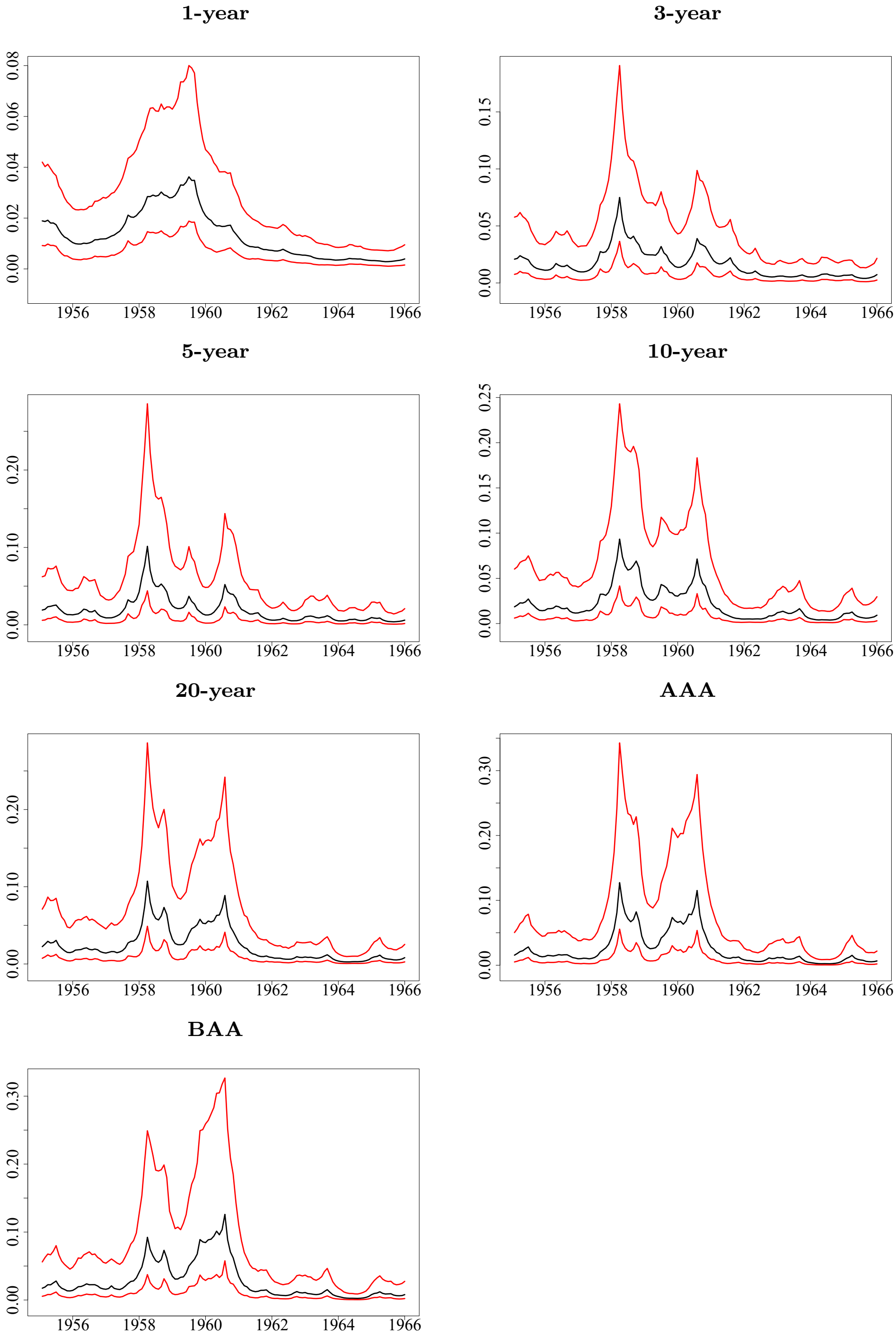

Figure A.1: Time varying volatilities of the residuals, posterior median (in black) along with the 80 percent highest posterior density interval (in red).

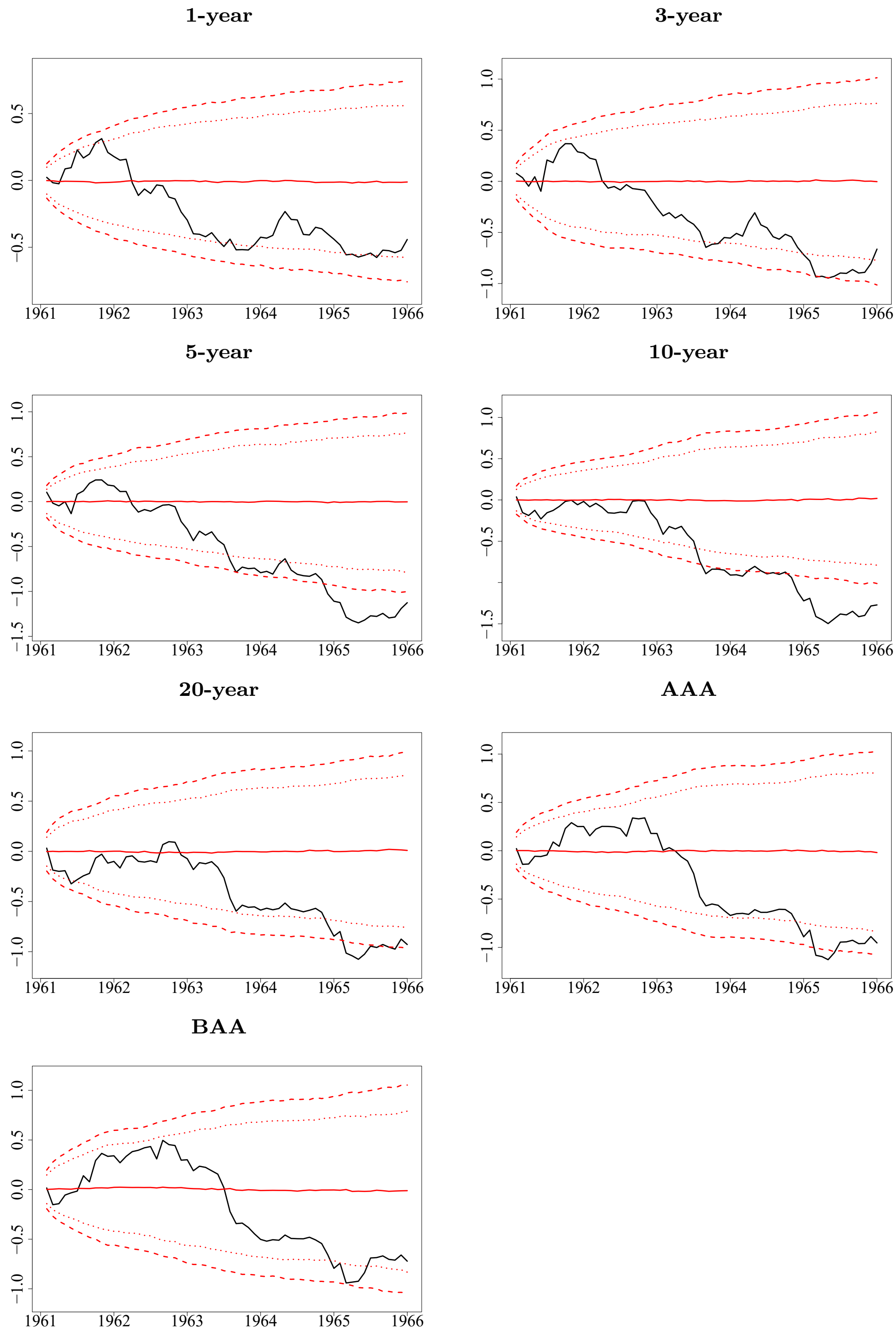

Figure A.2: Cumulative errors of the SV model.

A.2 A model with time varying parameters

While there is vast evidence for time varying volatility in the data, the model with stochastic volatility presented above cannot account for possible changes or breaks in the other parameters of the model. A break in the mean of the spread series would clearly jeopardize our method, as under such a misspecification, the model's error terms are unlikely to be centered on zero over the whole sample period. To control for such effects, we introduce an additional version of the model where the regression coefficients are also allowed to vary over time. To economize on the scale of the state space system, we use a model where the parameters possess a factor structure. The model applied here is an ARDL version of the FacTVP model proposed in Beyeler (2019); a more detailed explanation of the model structure, the prior distributions, and the Bayesian estimation techniques can be found therein. The TVP-ARDL model takes on the following form:

$$y_t^i = \beta_{0,t} + \beta_{c,t} X_t + \sum_{j=1}^{p} \beta_{j,t} X_{t-j} + u_t^i \tag{14}$$

$$\equiv Z_t b_t + u_t^i, \quad u_t^i \sim N(0, \sigma_t^2) \tag{15}$$

$$b_t = \lambda_0 + \lambda^f f_t \tag{16}$$

$$f_t = f_{t-1} + \eta_t^f \tag{17}$$

$$log(\sigma_t^2) = log(\sigma_{t-1}^2) + \eta_t^\sigma \tag{18}$$

Each regression coefficient collected in the vector b_t is the sum of two components: a constant component, λ_0, and a time varying component, $\lambda^f f_t$. The time variation is fully governed by a set of k factors, where k is chosen to be a small number compared to the total number of coefficients of the original regression model. The factors evolve as random walks, which is a common assumption in the TVP-VAR literature, as it allows the capture of temporary as well as permanent shifts (see, e.g., Cogley and Sargent (2005) or Primiceri (2005)). The driving forces of the factors η_t^f are assumed to be uncorrelated. Shrinkage priors are introduced to estimate λ_0 and the factor loadings, λ^f .

The cumulative errors of the TVP model shown in Figure A.3 do look different from those in the previous two models, but they seem to offer evidence of a negative effect of OT on the yield spread for U.S. Treasury securities.

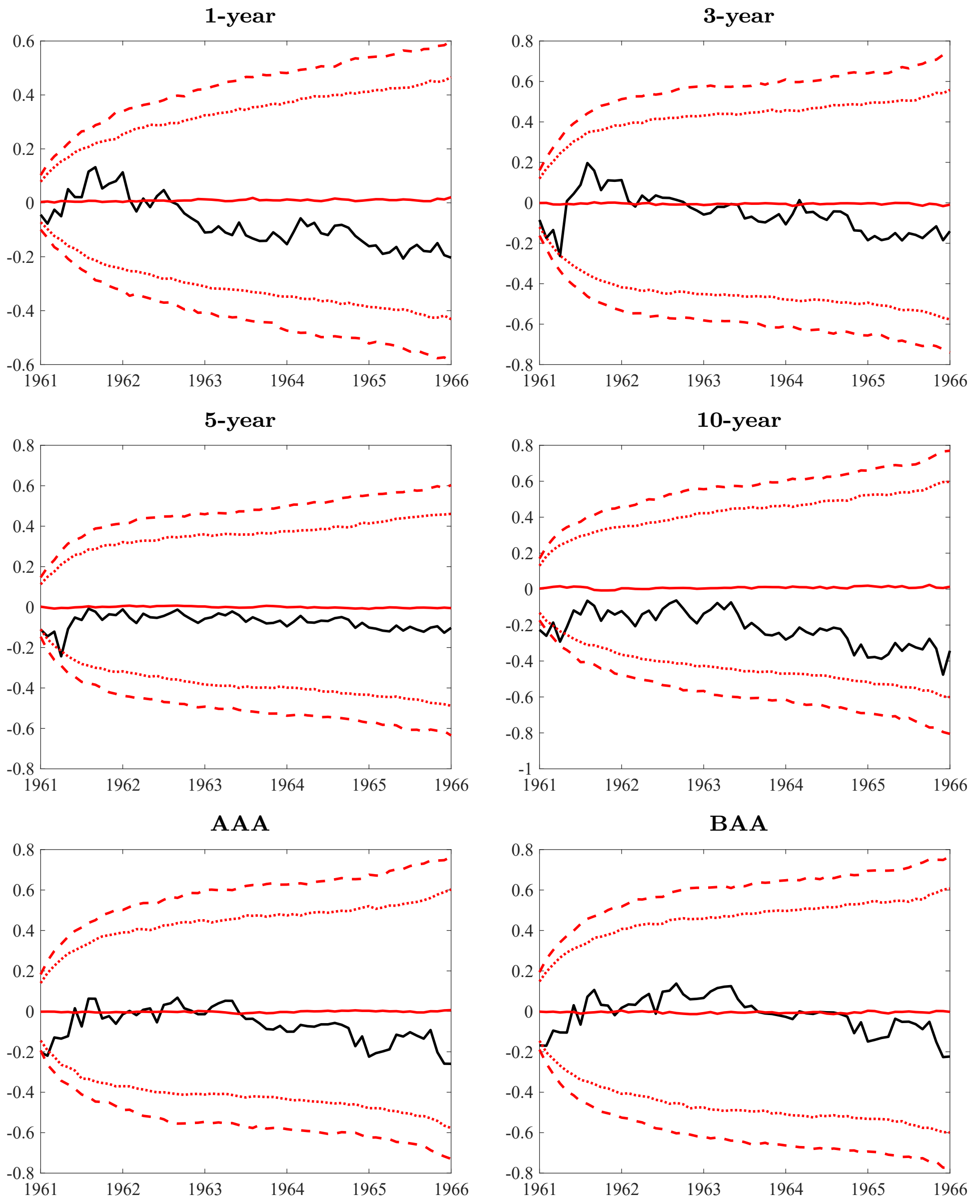

Figure A.3: Cumulative errors of the TVP model.

B Additional tables

Table B.1: Unit root tests: benchmark sample.

Variables	Lag order *p = 3*	*p = 6*	*p = 9*	*p = 12*
Unemployment rate	0.23	0.07	0.22	0.24
Capacity utilization	0.35	0.49	0.46	0.61
Vacancy rate	0.73	0.52	0.60	0.78
Inflation	0.00	0.08	0.39	0.40
3-month Treasury bill rate	0.18	0.22	0.42	0.25
Stock returns	0.00	0.00	0.02	0.02
Spreads with 3-month T-bill rate				
GS1	0.24	0.47	0.70	0.72
GS3	0.24	0.48	0.79	0.72
GS5	0.24	0.47	0.76	0.61
GS10	0.14	0.32	0.61	0.32
GS20	0.09	0.21	0.40	0.14
AAA	0.15	0.28	0.47	0.20
BAA	0.26	0.43	0.58	0.31
I-Bonds, Highest	0.12	0.24	0.44	0.17
I-Bonds, Lowest	0.21	0.39	0.54	0.25
I-Bonds (High Grade)	0.13	0.24	0.47	0.19
Fed. Housing Mortgages	0.32	0.41	0.69	0.43
P-Bonds, Highest	0.18	0.29	0.48	0.24
P-Bonds, Lowest	0.28	0.36	0.60	0.40
M-Bonds (High Grade)	0.40	0.58	0.79	0.53
M-Bonds, Highest	0.24	0.37	0.61	0.31
M-Bonds, Lowest	0.50	0.64	0.81	0.68
M-Bonds, 20 Bond Av.	0.22	0.38	0.67	0.33

Note: Bootstrapped p-values for Elliott, Rothenberg, and Stock unit root tests based on 10,000 bootstrap replications of estimated ARIMA processes. Tests are with no time trend for all series. I-Bonds denote industrial bonds, P-Bonds denote public utility bonds and M-Bonds denote municipal bonds.

Table B.2: Unit root tests: sample April 1953 - December 1974.

Variables	Lag order *p = 3*	*p = 6*	*p = 9*	*p = 12*
Unemployment rate	0.04	0.02	0.18	0.55
Capacity utilization	0.03	0.05	0.05	0.13
Vacancy rate	0.25	0.05	0.08	0.16
Inflation	0.11	0.88	0.94	0.78
3-month Treasury bill rate	0.59	0.48	0.51	0.33
Stock returns	0.00	0.00	0.00	0.01
Spreads with 3-month T-bill rate				
GS1	0.00	0.01	0.05	0.06
GS3	0.05	0.03	0.08	0.04
GS5	0.07	0.03	0.08	0.03
GS10	0.08	0.03	0.08	0.02
GS20	0.02	0.02	0.06	0.01
AAA	0.06	0.03	0.03	0.00
BAA	0.11	0.03	0.04	0.01

Note: Bootstrapped p-values for Elliott, Rothenberg, and Stock unit root tests based on 10,000 bootstrap replications of estimated ARIMA processes. Tests are with no time trend for all series. I-Bonds denote industrial bonds, P-Bonds denote public utility bonds and M-Bonds denote municipal bonds.

Table B.3: Long sample: variance of the residuals and R^2 of the estimated regressions.

Spreads of	Variance of u	R^2	10-90 perct.	adj. R^2	10-90 perct.
1-year	0.0104	0.834	[0.754;0.902]	0.794	[0.694;0.879]
3-year	0.0122	0.910	[0.842;0.940]	0.888	[0.804;0.925]
5-year	0.0100	0.948	[0.906;0.966]	0.936	[0.884;0.957]
10-year	0.0072	0.974	[0.954;0.983]	0.968	[0.944;0.979]
20-year	0.0042	0.988	[0.980;0.992]	0.986	[0.975;0.990]
AAA	0.0024	0.994	[0.989;0.996]	0.992	[0.986;0.995]
BAA	0.0019	0.996	[0.996;0.999]	0.996	[0.995;0.999]
I-Bonds, Highest	0.0039	0.989	[0.981;0.993]	0.986	[0.976;0.991]
I-Bonds (High Grade)	0.0038	0.990	[0.982;0.994]	0.987	[0.978;0.992]
P-Bonds, Highest	0.0031	0.992	[0.986;0.995]	0.990	[0.983;0.994]

Note: I-Bonds denote industrial bonds and P-Bonds denote public utility bonds.

Table B.4: Specification without the 3-month Treasury bill rate as control variable: variance of the residuals and R^2 of the estimated regressions.

Spreads of	Variance of u	R^2	10-90 perct.	adj. R^2	10-90 perct.
1-year	0.0106	0.826	[0.732;0.907]	0.782	[0.665;0.884]
3-year	0.0140	0.894	[0.849;0.960]	0.867	[0.811;0.951]
5-year	0.0166	0.907	[0.891;0.971]	0.884	[0.863;0.963]
10-year	0.0192	0.921	[0.923;0.980]	0.901	[0.904;0.975]
20-year	0.0208	0.934	[0.934;0.984]	0.918	[0.918;0.980]
AAA	0.0232	0.937	[0.938;0.984]	0.921	[0.922;0.980]
BAA	0.0227	0.957	[0.952;0.988]	0.946	[0.940;0.985]
I-Bonds, Highest	0.0232	0.930	[0.929;0.982]	0.912	[0.912;0.978]
I-Bonds, Lowest	0.0235	0.952	[0.946;0.987]	0.940	[0.933;0.984]
I-Bonds (High Grade)	0.0235	0.932	[0.926;0.982]	0.915	[0.908;0.978]
Fed. Housing Mortgages	0.0252	0.956	[0.946;0.987]	0.944	[0.932;0.984]
P-Bonds, Highest	0.0240	0.935	[0.933;0.984]	0.919	[0.916;0.980]
P- Bonds, Lowest	0.0228	0.947	[0.939;0.986]	0.934	[0.923;0.983]
M-Bonds (High Grade)	0.0242	0.956	[0.945;0.987]	0.944	[0.931;0.984]
M-Bonds, Highest	0.0243	0.942	[0.937;0.986]	0.928	[0.921;0.982]
M-Bonds, Lowest	0.0248	0.960	[0.950;0.989]	0.950	[0.937;0.986]
M-Bonds, 20 Bond Av.	0.0250	0.947	[0.940;0.985]	0.934	[0.925;0.982]

Note: I-Bonds denote industrial bonds, P-Bonds denote public utility bonds and M-Bonds denote municipal bonds.

C Additional figures

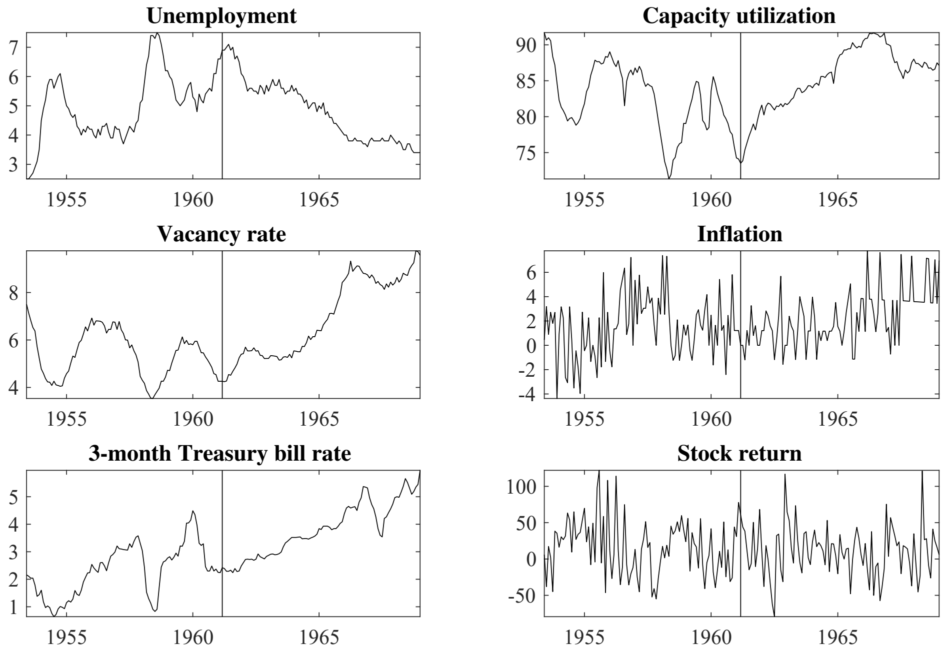

Figure C.1: Control variables included in the ARDL model.

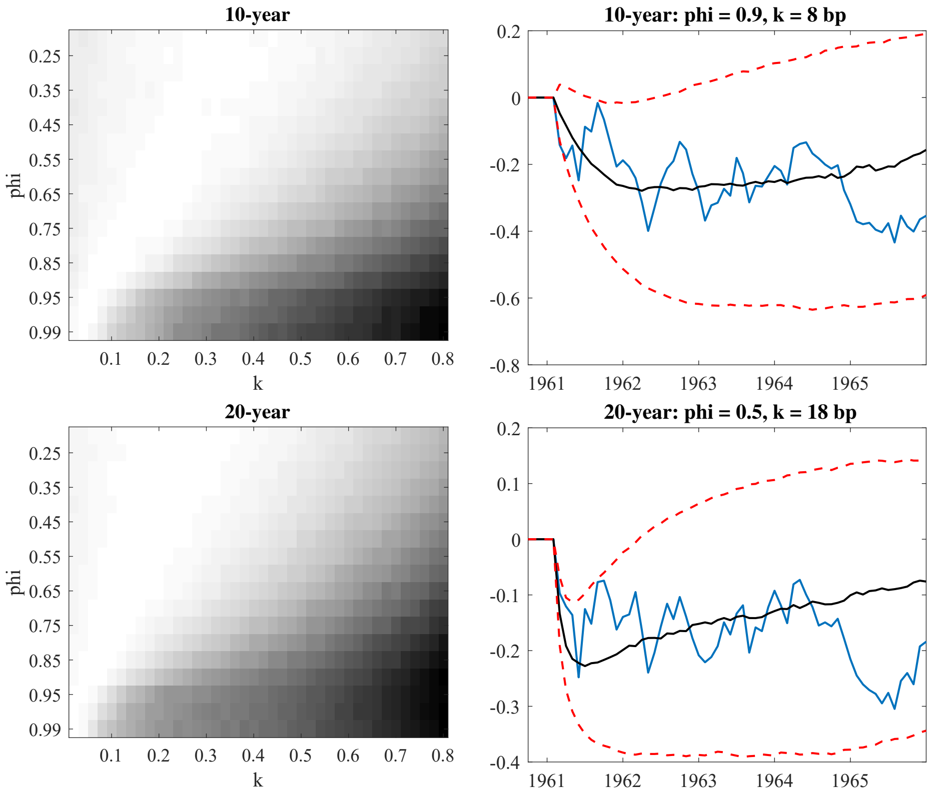

Figure C.2: Grid search results (cumulation since February 1961): heat map in which white areas indicate a close match (left) and cumulative errors of the original ARDL regression (in blue) together with the medians (in black) and the 10th and 90th percentiles (in red) of their closest match (right).

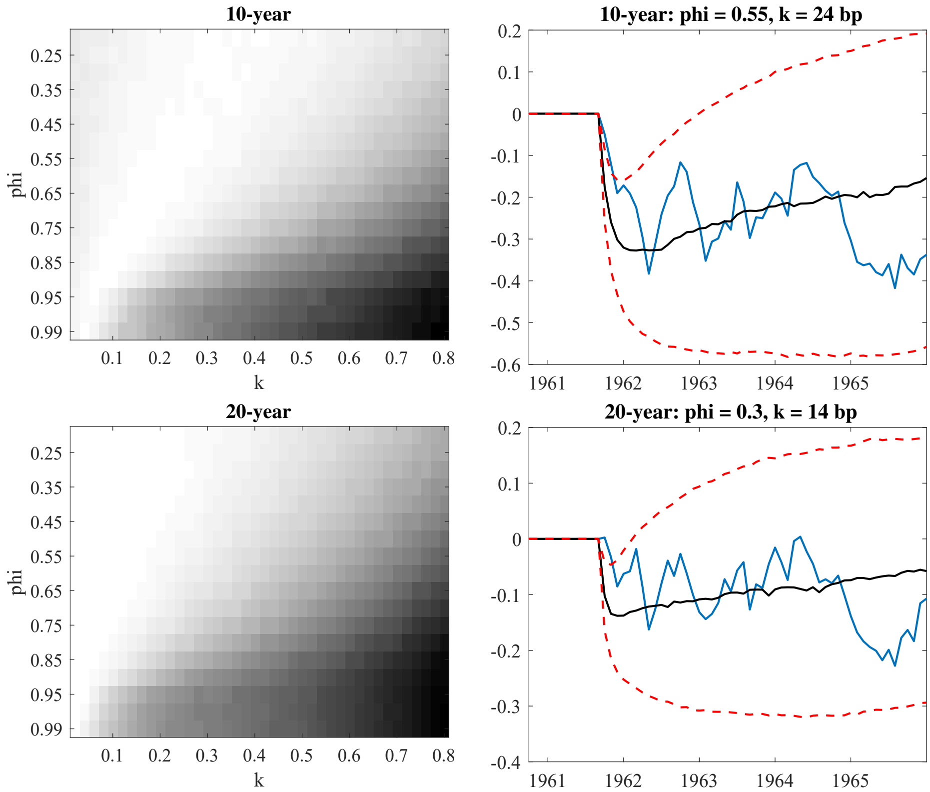

Figure C.3: Grid search results (cumulation since September 1961): heat map in which white areas indicate a close match (left) and cumulative errors of the original ARDL regression (in blue) together with the medians (in black) and the 10th and 90th percentiles (in red) of their closest match (right).

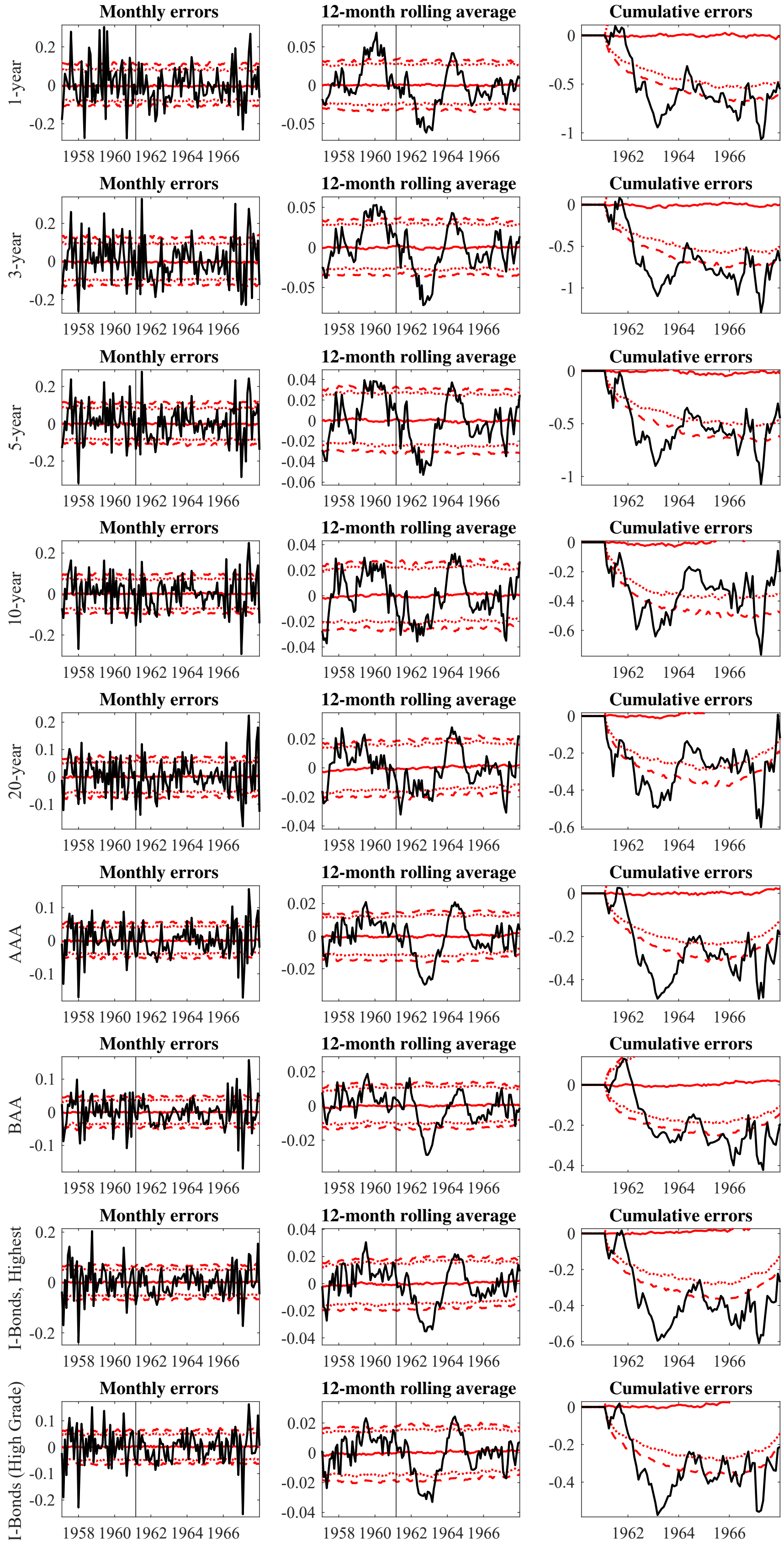

Figure C.4: Long sample: monthly errors, the 12-month rolling averages, and cumulative errors of the ARDL regressions along with the medians (red, solid), the 10th and 90th percentiles (red, dashed) and the 16th and 84th percentiles (red, dotted) bootstrapped under the null.

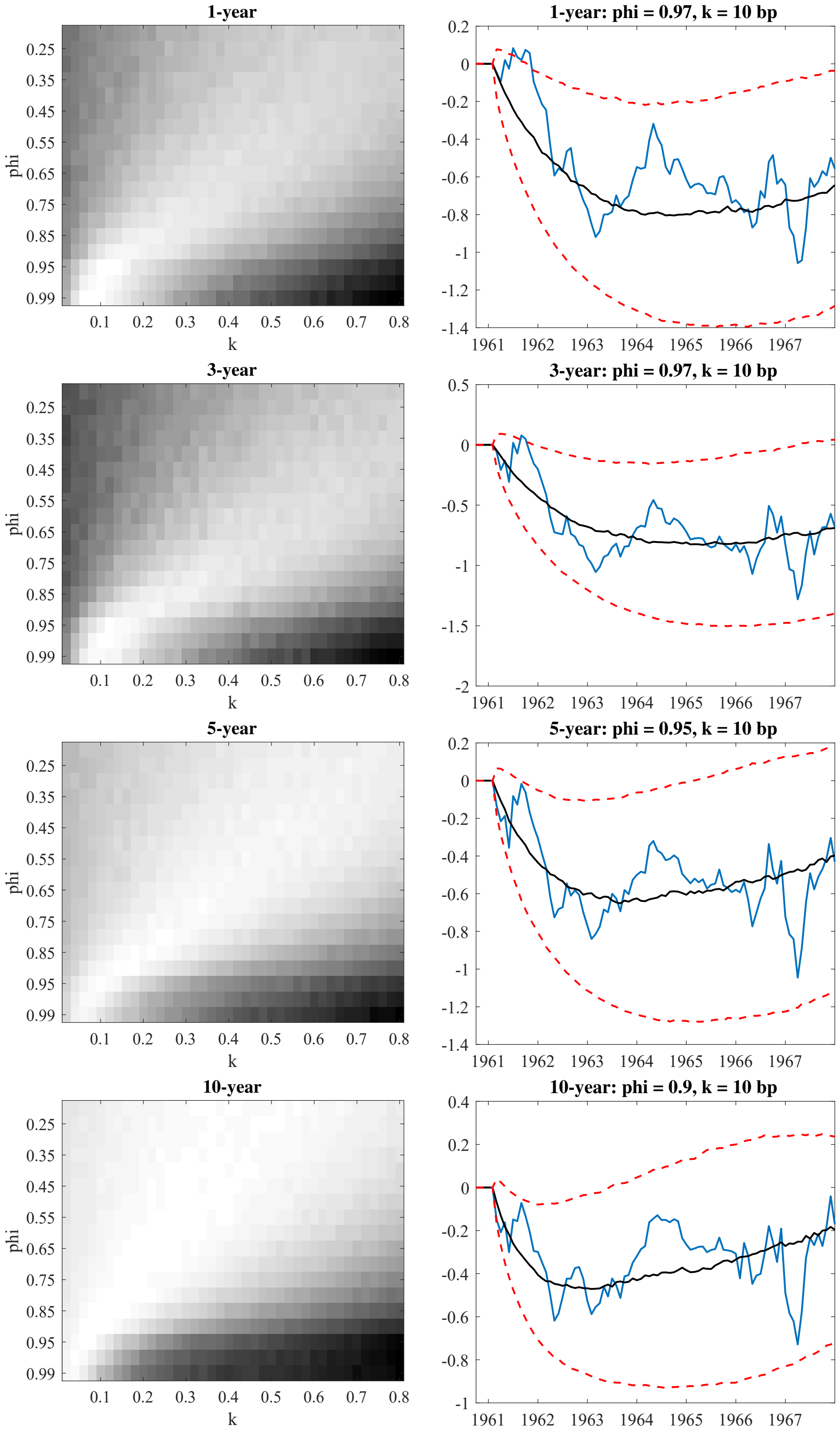

Figure C.5: Grid search results for long sample (cumulation since February 1961): heat map in which white areas indicate a close match (left) and cumulative errors of the original ARDL regression (in blue) together with the medians (in black) and the 10th and 90th percentiles (in red) of their closest match (right).

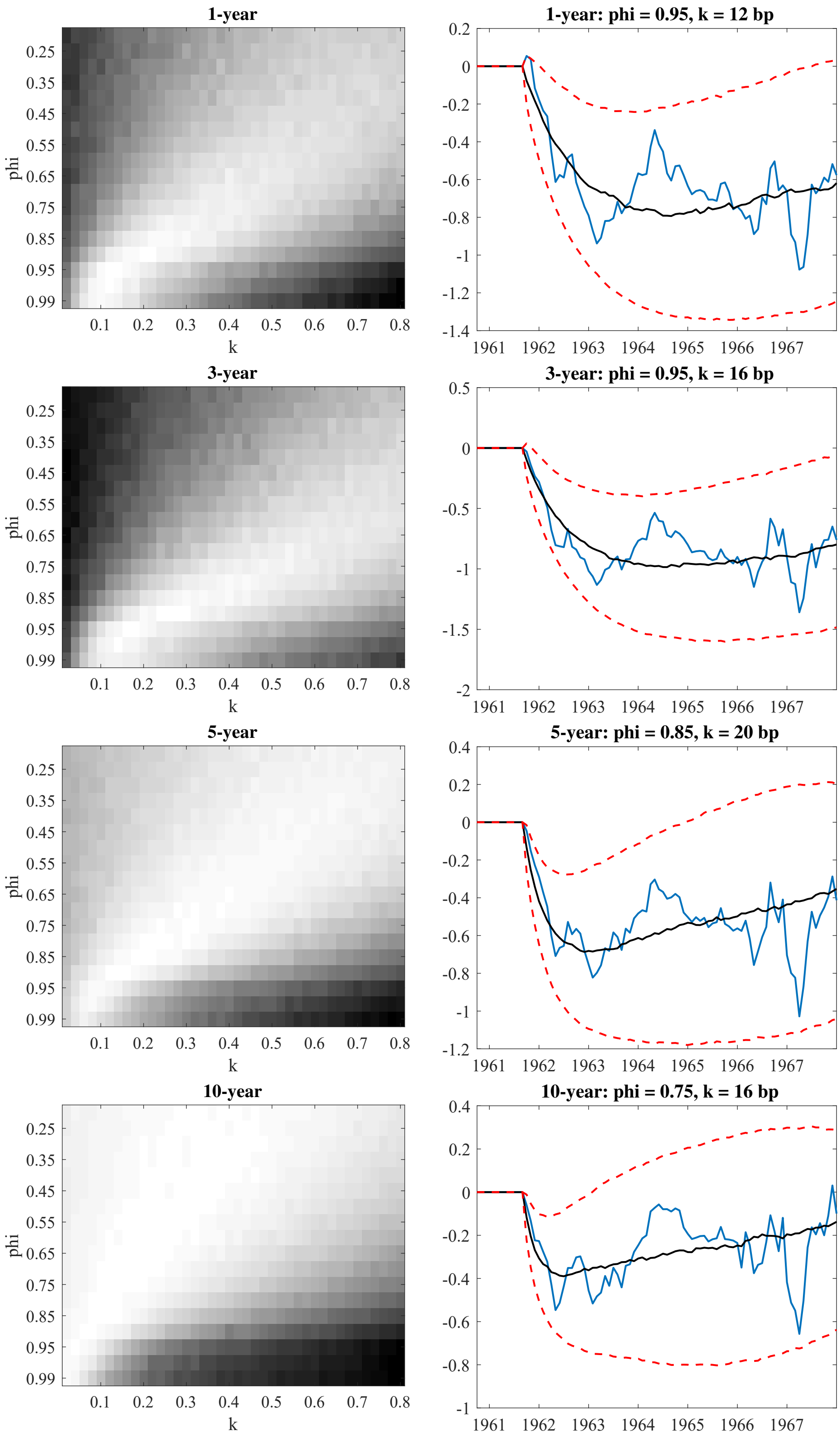

Figure C.6: Grid search results for long sample (cumulation since September 1961): heat map in which white areas indicate a close match (left) and cumulative errors of the original ARDL regression (in blue) together with the medians (in black) and the 10th and 90th percentiles (in red) of their closest match (right).

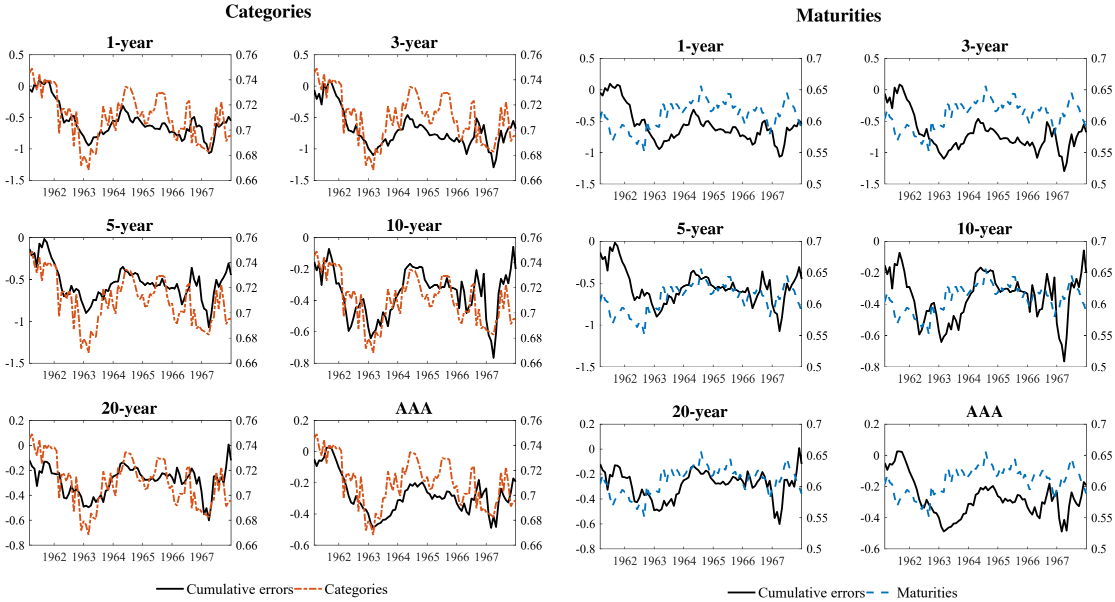

Figure C.7: Cumulative errors (in black) along with the share of long-term over total government securities in the hands of the public in terms of maturities (in blue) and categories (in red).

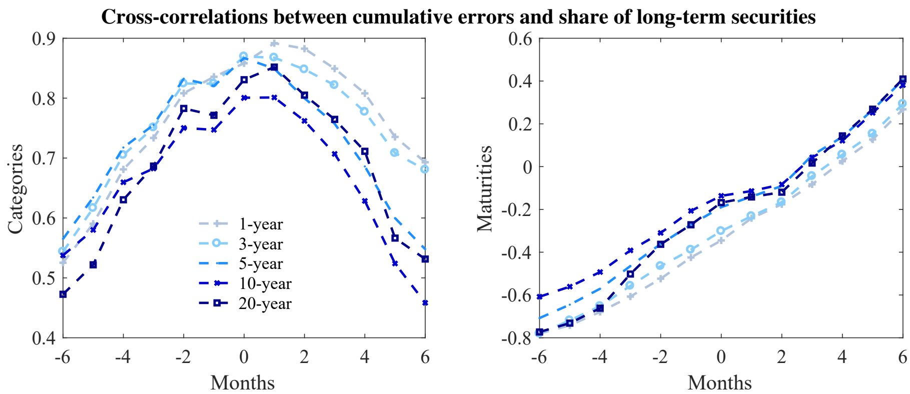

Figure C.8: Long sample: correlation between cumulative errors and relative supply measures during the OT period (February 1961 - December 1963) for the category (left panel) and maturity definition (right panel).

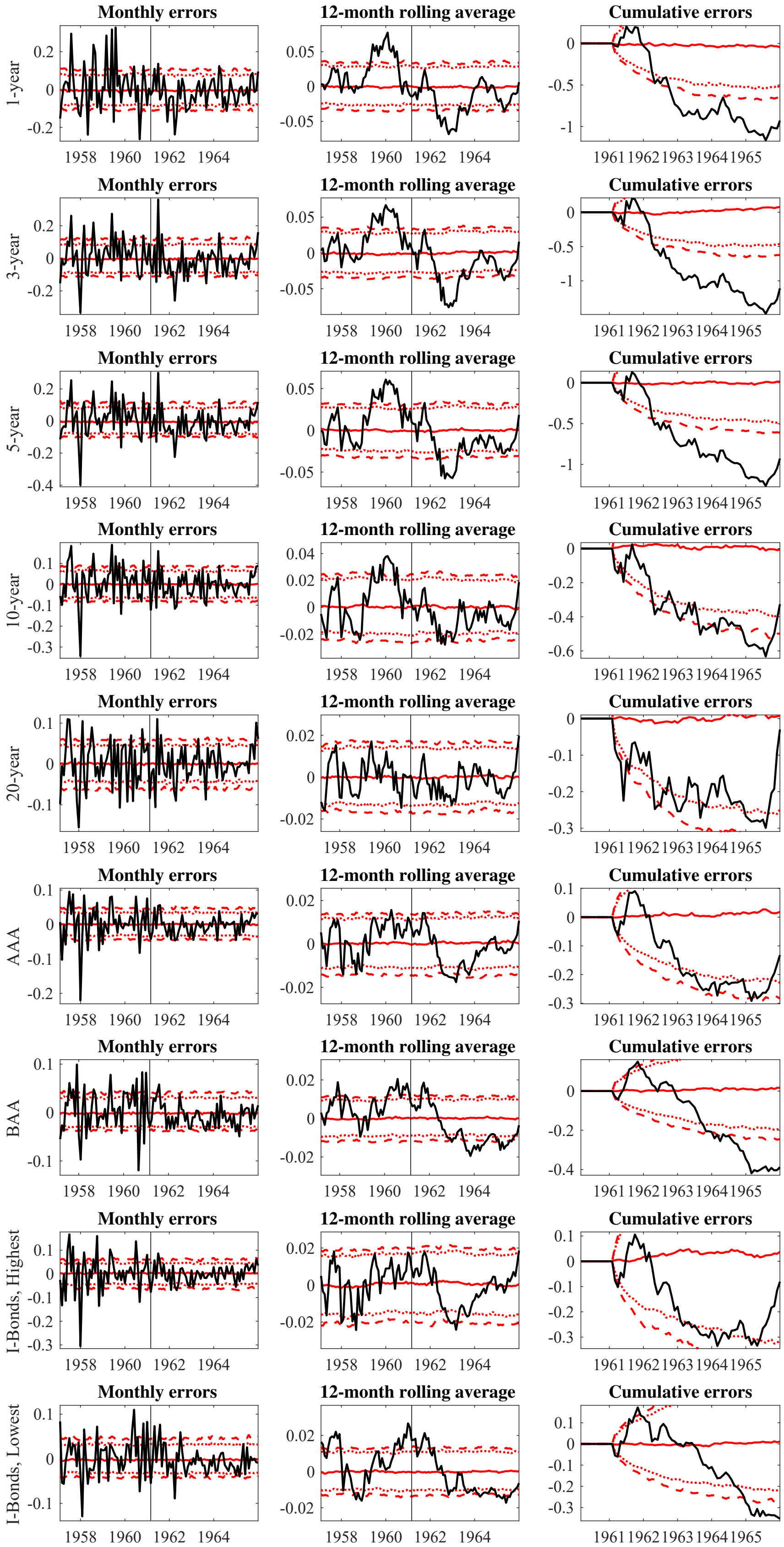

Figure C.9: Specification with unemployment, inflation and 3-month Treasury bill rate as control variables: monthly errors, the 12-month rolling averages, and cumulative errors of the ARDL regressions along with the median (red, solid), the 10th and 90th percentiles (red, dashed) and the 16th and 84th percentiles (red, dotted) bootstrapped under the null.

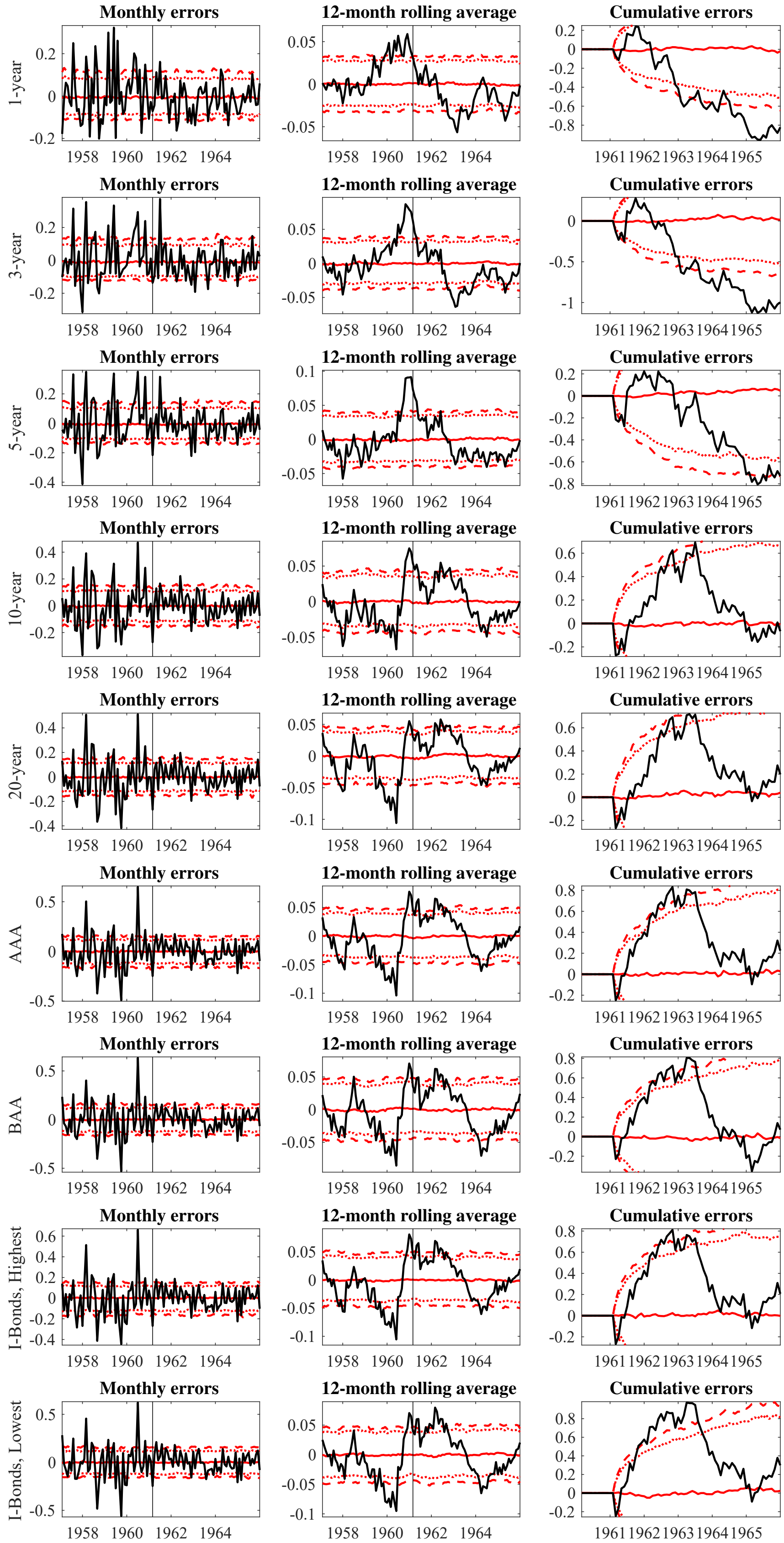

Figure C.10: Specification without 3-month Treasury bill rate as control variable: monthly errors, the 12-month rolling averages, and cumulative errors of the ARDL regressions along with the medians (red, solid), the 10th and 90th percentiles (red, dashed) and the 16th and 84th percentiles (red, dotted) bootstrapped under the null.

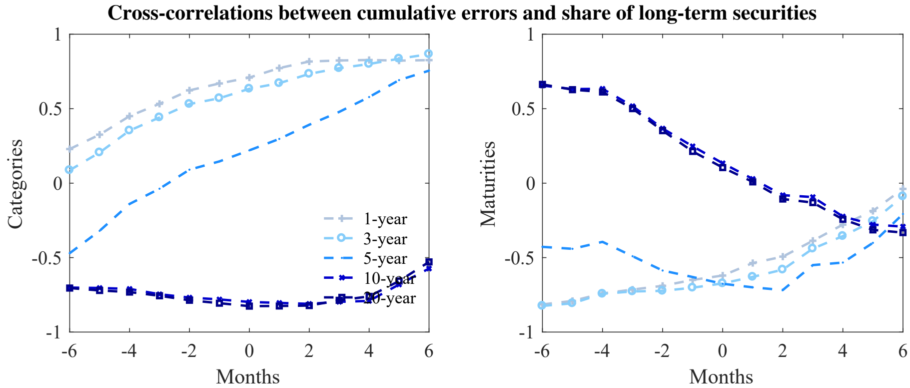

Figure C.11: Specification without 3-month Treasury bill rate as control variable: correlation between cumulative errors and relative supply measures during the OT period (February 1961 - December 1963) for the category (left panel) and maturity definition (right panel).

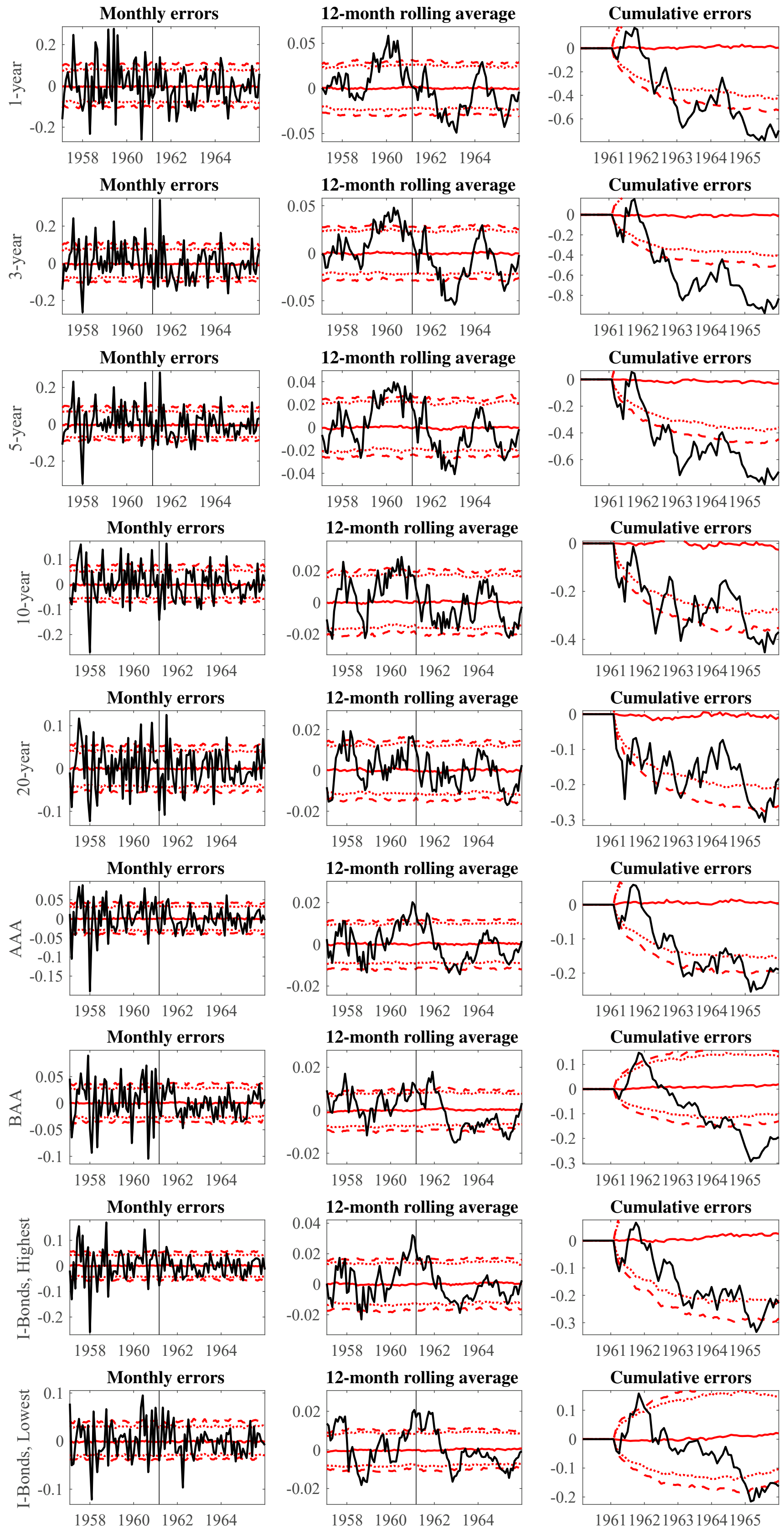

Figure C.12: Specification with rates instead of spreads: monthly errors, the 12-month rolling averages, and cumulative errors of the ARDL regressions along with the median (red, solid), the 10th and 90th percentiles (red, dashed) and the 16th and 84th percentiles (red, dotted) bootstrapped under the null.

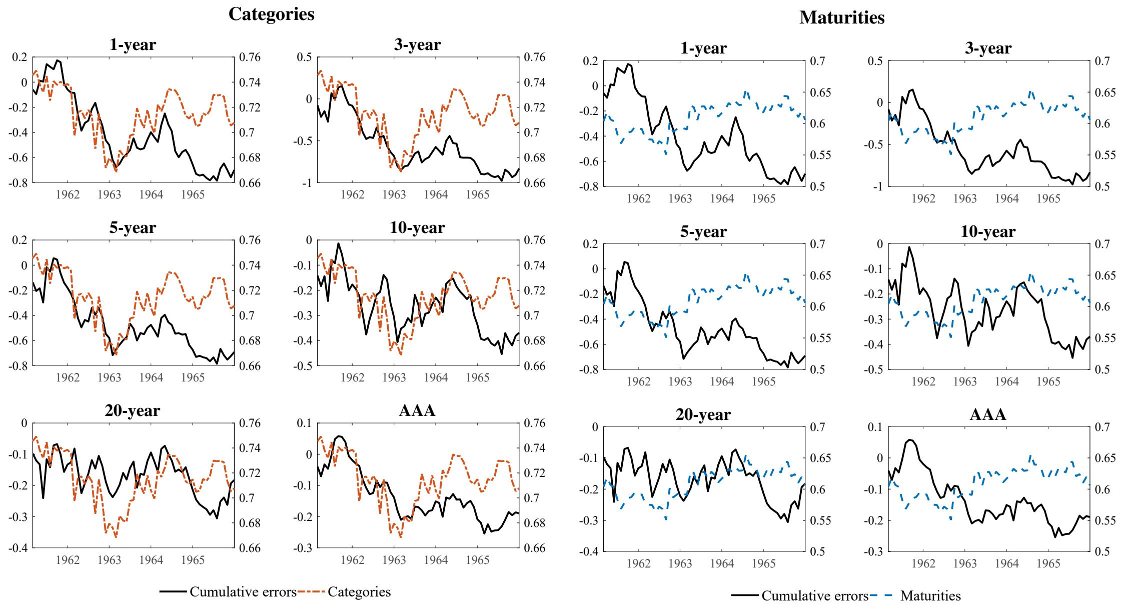

Figure C.13: Cumulative errors (in black) along with the share of long-term over total government securities in the hands of the public in terms of maturities (in blue) and categories (in red).

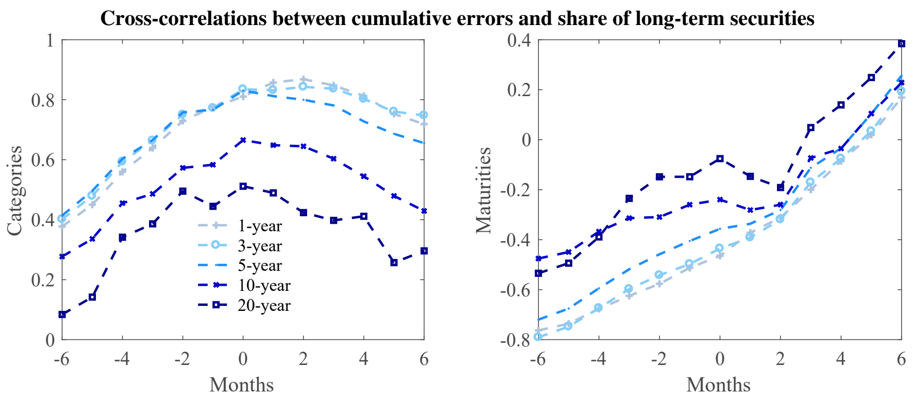

Figure C.14: Specification with rates instead of spreads: correlation between cumulative errors and relative supply measures during the OT period (February 1961 - December 1963) for the category (left panel) and maturity definition (right panel).

D Data

D.1 Fed balance sheet data

The balance sheet data containing the Fed's holdings of U.S. government securities is available at weekly frequency in pdf format from the FRASER database: `https://fraser.stlouisfed.org/title/83`. We extract government security holdings according to their category as well as their maturity structure for the time span December 1957 up to June 1996. The data from June 1996 onward are available in electronic format from `https://www.federalreserve.gov/releases/h41/`. We convert the series to monthly frequency by averaging the weekly holdings of a given month.

D.2 Treasury balance sheet data

The balance sheet data for the U.S. Treasury are available at monthly frequency in pdf format from `https://www.treasurydirect.gov/govt/reports/pd/mspd/mspd.htm`. We extract the total amount of outstanding Treasury securities according to their category for the period January 1933 to September 2017 and the corresponding maturity structure for the period December 1957 to September 2017 (the maturity structure is not available prior to December 1957).

D.3 Interest rate series and control variables

The 1-, 3-, 5-, 10- and 20-year Treasury constant maturity rates are the GS1-GS20 series from the H.15 release of the Board of Governors of the Federal Reserve System. The AAA and BAA rates are Moody's seasoned AAA and BAA corporate bond yields, which are both available from FRED of the Federal Reserve Bank of St. Louis. All the remaining interest rate series are from the NBER Macrohistory Database. The yields on industrial bonds (I-Bonds) are the M13059USM156NNBR (highest rating – AAA grade bonds) and M13060USM156NNBR (lowest rating – BAA grade bonds) series. The yield on high grade industrial bonds (AAA rating) is the M13026USM156NNBR series. This series is the average of the four or five weekly Standard and Poor's AAA indexes. The yields on federal housing mortgages are the secondary market yields on federal housing administration mortgages (M13045USM156NNBR). The yields on public utility bonds (P-Bonds) are the M13063USM156NNBR series (highest rating - AAA grade) and the M13064USM156NNBR series (lowest rating - BAA grade). The yields on municipal bonds (M-Bonds) are the M13043USM156NNBR (highest rating - AAA grade bonds) and M13065USM156NNBR (lowest rating - BAA grade bonds) series. The yield on high grade municipal bonds (M-Bonds) is the M13023USM156NNBR series. The yield on municipal bonds, 20 bond average, is the M13050USM156NNBR series.

The unemployment rate is the civilian unemployment rate (UNRATE) from the U.S. Department of Labor's Bureau of Labor Statistics. Capacity utilization is the CUMFNS series available from the G.17 release of the Board of Governors of the Federal Reserve System. Inflation is computed as the annualized month-on-month growth rate of the consumer price index for all urban consumers, which is the

CPIAUCSL series from the Bureau of Labor Statistics. The vacancy rate is defined as the ratio between the help wanted index (U.S. Index of Help Wanted Advertising VOLA) and the civilian labor force (CLF16OV), which is available from the U.S. Department of Labor's Bureau of Labor Statistics. Real stock returns are computed as the month-on-month growth rate of real stock prices, where real stock prices are the Standard & Poor's (S&P) 500 index deflated by the consumer price index. The S&P 500 index is available at `http://www.multpl.com/s-p-500-historical-prices/table/by-month`.

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