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Understanding Swiss Real Interest Rates in a Financially Globalized World

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Understanding Swiss Real Interest Rates in a Financially Globalized World

Summary

The objective of this paper is to understand the evolution of real interest rates in Switzerland from a global perspective. While we take a long-term perspective, starting in the nineteenth century, the focus of our analysis is on the more recent period.

The first part of the study estimates carefully ex ante real interest rates in Switzerland and in other developed economies and describes their relative evolution. Our results highlight the decline in – and convergence of – global real interest rates that has unfolded over the last three decades, for all maturities. The reasons behind this decline include in particular an increase in global saving, e.g., due to demographic or precautionary saving reasons, and a decline in global investment, e.g., due to lower productivity or higher uncertainty. We also document the convergence of national interest rates. This phenomenon, that reflects growing integration in international financial markets, reduces the relative importance of national factors to account for real interest rate movements.

On average over the last century, Swiss yields stand out as being particularly low and stable. However, we find that interest rates in Switzerland have fallen less than in many other countries during the last decade. The second part of the paper examines this issue in details and attempts to provide explanations. We argue that the smaller decline in real rates in Switzerland is related to the Effective Lower Bound (ELB) on short-term nominal interest rates and to the strong Swiss franc.

The fact that most central banks have reduced their policy rates near zero, i.e. close to the ELB, has mechanically reduced the dispersion across nominal rates. Starting from lower levels, nominal Swiss yields decreased less than in other countries. Subdued inflation expectations in Switzerland have further contributed to the lower decline in real rates. In particular, although nominal Swiss yields have been slightly lower than German ones, the position of associated real rates has been inverted over the last five years because of lower Swiss inflation expectations over this period.

We then examine whether the reduction in the interest differential is related to a lower attractiveness of the Swiss franc. The real interest rate differential is made of three elements: a risk premium, the expected real exchange rate depreciation and the relative convenience yield on government bonds. Focusing on the difference of Swiss minus German real government bonds yields, we find a significant increase in expected real depreciation of the Swiss franc and a somewhat lower convenience yield for Swiss bonds. In contrast, the risk premium in favor of the Swiss franc increased and therefore cannot explain the smaller decline in real interest rates in Switzerland.

The last part of the paper analyzes the negative convenience yield on Swiss government bonds and its recent decline. We examine the hypothesis that the convenience yield of the Swiss franc results from the relative supply of and the relative demand for Swiss and foreign government bonds. We show that both government bonds purchases by foreign central banks and SNB foreign exchange interventions may have contributed to this decline. Interestingly, we also find that an exchange rate appreciation leads to a decline in the convenience yield. This can be explained by the fact that an exchange rate appreciation increases the foreign currency value of Swiss government bonds, which reduces the convenience yield by making Swiss bonds less scarce.

Die Schweizer Realzinsen in einer finanziell globalisierten Welt

Zusammenfassung

Das Ziel dieser Arbeit ist es, die Entwicklung der Realzinsen in der Schweiz aus einer globalen Perspektive zu verstehen. Während unsere langfristige Perspektive den gesamten Zeitraum von Beginn des neunzehnten Jahrhunderts miteinbezieht, liegt der Schwerpunkt unserer Analyse auf den aktuelleren Perioden.

Im ersten Teil der Studie werden die realen Zinssätze in der Schweiz und in anderen entwickelten Volkswirtschaften sorgfältig ex ante geschätzt und ihre relative Entwicklung beschrieben. Unsere Ergebnisse verdeutlichen den Rückgang sowie die Konvergenz der globalen Realzinsen, die in den letzten drei Jahrzehnten für alle Laufzeiten festzustellen sind. Zu den Gründen für den Rückgang gehören insbesondere ein Anstieg der globalen Ersparnisse, z.B. aus demografischen oder vorsorglichen Gründen, und ein Rückgang der globalen Investitionen, z.B. aufgrund geringerer Produktivität oder höherer Unsicherheit. Wir dokumentieren auch eine Konvergenz der nationalen Zinssätze. Dieses Phänomen, das die zunehmende Integration in die internationalen Finanzmärkte widerspiegelt, vermindert die relative Bedeutung, die nationalen Faktoren für die Erklärung von Bewegungen der Realzinsen zugeordnet werden können.

Im Durchschnitt des letzten Jahrhunderts heben sich die Schweizer Renditen als besonders niedrig und stabil hervor. Wir stellen jedoch fest, dass die Zinssätze in der Schweiz im letzten Jahrzehnt weniger stark gesunken sind als in vielen anderen Ländern. Der zweite Teil dieser Arbeit untersucht dies im Detail und beschreibt mögliche Erklärungsansätze. Wir argumentieren, dass der geringere Realzinsrückgang in der Schweiz mit der effektiven Untergrenze (der sog. Effective Lower Bound, ELB) für kurzfristige Nominalzinsen und mit dem starken Schweizer Franken zusammenhängt.

Die Tatsache, dass die meisten Zentralbanken ihre Leitzinsen in die Nähe von Null, d.h. nahe der ELB, gesenkt haben, hat die Streuung der Nominalzinsen mechanisch reduziert. Ausgehend von einem niedrigeren Niveau sind die nominalen Renditen in der Schweiz weniger stark gesunken als in anderen Ländern. Die gedämpften Inflationserwartungen in der Schweiz haben weiter zum geringeren Rückgang der realen Renditen beigetragen. Insbesondere war die Position der zugehörigen realen Renditen in den letzten fünf Jahren aufgrund der niedrigeren Schweizer Inflationserwartungen in diesem Zeitraum invertiert, und dies obwohl die nominalen Schweizer Renditen etwas niedriger waren als die deutschen Renditen.

Anschliessend untersuchen wir, ob die Verringerung der Zinsdifferenz mit einem Attraktivitätsverlust des Schweizer Frankens zusammenhängt. Die Realzinsdifferenz setzt sich aus drei Elementen zusammen: einer Risikoprämie, der erwarteten realen Wechselkursabwertung und der relativen Verfügbarkeitsprämie (die sog. Convenience Yield) von Staatsanleihen. Wenn wir uns auf die Differenz der realen Renditen von Schweizer zu deutschen Staatsanleihen konzentrieren, finden wir einen signifikanten Anstieg der erwarteten realen Abwertung des Schweizer Frankens und eine etwas niedrigere Verfügbarkeitsprämie für Schweizer Anleihen. Die Risikoprämie zu Gunsten des Schweizer Frankens ist dagegen gestiegen und kann daher den geringeren Rückgang der Realzinsen in der Schweiz nicht erklären.

Der letzte Teil analysiert die negative Verfügbarkeitsprämie von Schweizer Staatsanleihen und ihren jüngsten Rückgang. Wir untersuchen die Hypothese, dass die Verfügbarkeitsprämie des Schweizer Frankens aus dem relativen Angebot an und der relativen Nachfrage nach Schweizer und ausländischen Staatsanleihen resultiert. Wir zeigen auf, dass sowohl die Käufe von Anleihen durch ausländische Zentralbanken als auch die Devisenmarktinterventionen der SNB zu diesem Rückgang beigetragen haben könnten. Interessanterweise stellen wir auch fest, dass eine Aufwertung des Wechselkurses zu einem Rückgang der Verfügbarkeitsprämie führt. Dies lässt sich dadurch erklären, dass eine Wechselkursaufwertung den Fremdwährungswert von Schweizer Anleihen erhöht, was die Verfügbarkeitsprämie reduziert, da Schweizer Anleihen weniger knapp werden.

Comprendre les taux d’intérêt réels suisses dans un monde financièrement globalisé

Résumé

L’objectif de cet article est de comprendre l’évolution des taux d’intérêt réels en Suisse dans une perspective mondiale. Bien que nous adoptions une perspective de long terme, en commençant par le XIXe siècle, notre analyse se concentre sur la période la plus récente.

La première partie de l’étude estime soigneusement les taux d’intérêt réels ex ante en Suisse et dans d’autres économies développées et décrit leur évolution relative. Nos résultats mettent en évidence la baisse – et la convergence – des taux d’intérêt réels mondiaux qui s’est déroulée au cours des trois dernières décennies, pour toutes les échéances. Les raisons de cette baisse comprennent notamment une augmentation de l’épargne mondiale, par exemple pour des raisons démographiques ou d’épargne de précaution, et une baisse de l’investissement mondial, par exemple en raison d’une baisse de la productivité ou d’une plus grande incertitude. Nous documentons également la convergence des taux d’intérêt nationaux. Ce phénomène, qui reflète une intégration croissante sur les marchés financiers internationaux, réduit l’importance relative des facteurs nationaux pour expliquer les mouvements des taux d’intérêt réels.

En moyenne sur le siècle dernier, les rendements suisses se distinguent comme étant particulièrement bas et stables. Cependant, nous constatons que les taux d’intérêt en Suisse ont moins baissé que dans de nombreux autres pays au cours de la dernière décennie. La deuxième partie du document examine cette question en détail et tente de fournir des explications. Nous soutenons que la baisse plus faible des taux réels en Suisse est liée à la limite inférieure effective des taux d’intérêt nominaux à court terme et à la force du franc suisse.

Le fait que la plupart des banques centrales aient réduit leurs taux directeurs à un niveau proche de zéro, c’est-à-dire proche de la limite inférieure effective, a mécaniquement réduit la dispersion des taux nominaux. Partant de niveaux plus bas, les rendements nominaux suisses ont moins diminué que dans d’autres pays. La faiblesse des anticipations d’inflation en Suisse a également contribué à la baisse plus faible des taux réels. En particulier, bien que les rendements nominaux suisses aient été légèrement inférieurs à ceux de l’Allemagne, la position des taux réels associés s’est inversée au cours des cinq dernières années en raison de la baisse des anticipations d’inflation en Suisse sur cette période.

Nous examinons ensuite si la réduction du différentiel d’intérêt est liée à une moindre attractivité du franc suisse. L’écart de taux d’intérêt réels est composé de trois éléments : une prime de risque, la dépréciation réelle attendue du taux de change et le rendement relatif d’opportunité des obligations d’État. En nous concentrant sur la différence entre les rendements réels des obligations d’État suisses et allemandes, nous constatons une augmentation significative de la dépréciation réelle attendue du franc suisse et un rendement d’opportunité légèrement inférieur pour les obligations suisses. En revanche, la prime de risque en faveur du franc suisse a augmenté et ne peut donc pas expliquer la baisse plus faible des taux d’intérêt réels en Suisse.

La dernière partie de l’article analyse le rendement d’opportunité négatif des obligations du gouvernement suisse et sa récente baisse. Nous examinons l’hypothèse selon laquelle le rendement d’opportunité du franc suisse résulte de l’offre relative et de la demande relative d’obligations d’État suisses et étrangères. Nous montrons que les achats d’obligations d’État par les banques centrales étrangères et les interventions de change de la BNS peuvent avoir contribué à cette baisse. Il est intéressant de noter que nous constatons également qu’une appréciation du taux de change entraîne une baisse du rendement d’opportunité. Cela peut s’expliquer par le fait qu’une appréciation du taux de change augmente la valeur en devises des obligations d’État suisses, ce qui réduit le rendement d’opportunité en rendant les obligations suisses moins rares.

Comprendere i tassi di interesse reali svizzeri in un mondo finanziariamente globalizzato

Riassunto

L’obiettivo di questo articolo è capire l’evoluzione dei tassi di interesse reali in Svizzera da una prospettiva globale. Pur adottando una prospettiva a lungo termine, a partire dal diciannovesimo secolo, la nostra analisi si concentra sul periodo più recente.

La prima parte dello studio stima accuratamente i tassi d’interesse reali ex ante in Svizzera e in altre economie sviluppate e descrive la loro evoluzione relativa. I nostri risultati evidenziano il declino – e la convergenza – dei tassi d’interesse reali globali che si è verificato negli ultimi tre decenni, per tutte le scadenze. Le ragioni dietro questo declino includono in particolare un aumento del risparmio globale, ad esempio per motivi demografici o di risparmio precauzionale, e un calo degli investimenti globali, ad esempio a causa di una minore produttività o di una maggiore incertezza. Documentiamo anche la convergenza dei tassi di interesse nazionali. Questo fenomeno, che riflette la crescente integrazione nei mercati finanziari internazionali, riduce l’importanza relativa dei fattori nazionali per spiegare i movimenti dei tassi di interesse reali.

In media nell’ultimo secolo, i rendimenti svizzeri si distinguono per essere particolarmente bassi e stabili. Tuttavia, troviamo che i tassi di interesse in Svizzera si sono ridotti meno che in molti altri paesi durante l’ultimo decennio. La seconda parte dell’articolo esamina questo problema in dettaglio e cerca di fornire delle spiegazioni. Sosteniamo che il minor calo dei tassi reali in Svizzera è legato al limite inferiore effettivo (Effective Lower Bound, ELB) sui tassi d’interesse nominali a breve termine e al forte franco svizzero.

Il fatto che la maggior parte delle banche centrali abbia ridotto i propri tassi d’interesse vicino allo zero, cioè vicino all’ELB, ha ridotto meccanicamente la dispersione dei tassi nominali. Partendo da livelli più bassi, i rendimenti nominali svizzeri sono diminuiti meno che in altri paesi. Le ridotte aspettative di inflazione in Svizzera hanno ulteriormente contribuito al minor calo dei tassi reali. In particolare, sebbene i rendimenti nominali svizzeri siano stati leggermente inferiori a quelli tedeschi, la posizione dei tassi reali associati è stata invertita negli ultimi cinque anni a causa delle minori aspettative di inflazione svizzere in questo periodo.

Esaminiamo poi se la riduzione del differenziale d’interesse è legata a una minore attrattiva del franco svizzero. Il differenziale di interesse reale è composto da tre elementi: un premio di rischio, il deprezzamento atteso del tasso di cambio reale e il rendimento di convenienza relativo dei titoli di stato. Concentrandoci sulla differenza dei rendimenti dei titoli di stato reali svizzeri rispetto a quelli tedeschi, troviamo un aumento significativo del deprezzamento reale atteso del franco svizzero e un rendimento di convenienza leggermente inferiore per le obbligazioni svizzere. Al contrario, il premio di rischio a favore del franco svizzero è aumentato e quindi non può spiegare il minore calo dei tassi di interesse reali in Svizzera.

L’ultima parte dell’articolo analizza il rendimento di convenienza negativo dei titoli di stato svizzeri e il suo recente calo. Esaminiamo l’ipotesi che il rendimento di convenienza del franco svizzero derivi dall’offerta relativa e dalla domanda relativa di titoli di stato svizzeri ed esteri. Mostriamo che sia gli acquisti di titoli di stato da parte di banche centrali estere che gli interventi in valuta estera della BNS possono aver contribuito a questo declino. È interessante notare che troviamo anche che un apprezzamento del tasso di cambio porta a un calo del rendimento di convenienza. Ciò può essere spiegato dal fatto che un apprezzamento del tasso di cambio aumenta il valore in valuta estera dei titoli di stato svizzeri, il che riduce il rendimento di convenienza rendendo meno scarse le obbligazioni svizzere.

Contents

1 Introduction

The objective of this paper is to understand the evolution of real interest rates in Switzerland from a global perspective. The secular decline in global real interest rates is a well-documented fact. This phenomenon alone puts a downward pressure on Swiss real interest rates. In addition to that, the Swiss franc is considered as a safe haven currency, which may also depress the Swiss interest rate. The first part of the paper estimates carefully ex ante real interest rates in Switzerland and in other developed economies and describes their relative evolution. While we take a long-term perspective, starting in the nineteenth century, the focus of our analysis is on the more recent period. Surprisingly, we find that in the recent decade real interest rates in Switzerland have fallen less than in many other countries, while at the same time the Swiss franc has fully played its role as safe haven with a substantial real appreciation. The second part of the paper examines these issues in detail and attempts to provide explanations. We show that the smaller decline in real rates in Switzerland is related to the strong Swiss franc and the Effective Lower Bound on short-term nominal interest rates.

The first part of our empirical analysis is based on a long and wide historical dataset of real interest rates. Specifically, we compute real interest rates on government bonds at different maturities for 17 countries from 1880 to 2020. The real rates are obtained by subtracting inflation expectations from nominal yields with matching time periods, countries, and maturities. First, to obtain the nominal yields, we employ filtering procedures to interpolate nominal yields coming from different sources, including the macrohistory database of Jordà et al. (2015). Second, inflation adjustments—i.e., inflation expectations—are inferred from an approach involving econometric specifications posited for the inflation process and survey-based forecasts (as in Grishchenko et al., 2019; Aruoba, 2020).

Our results highlight the decline in—and convergence of—global real interest rates that has unfolded over the last three decades, for all maturities. Except for the world war periods, the 10-year global real rate was on average equal to 3% from the late 19th century to the 1970s. It then rose to levels above 5% and started to steadily decline from the early 1990s, by about 5 percentage points. Global real interest rates have been negative over the last five years. The reasons behind this decline have been widely analyzed. They include in particular an increase in global saving, e.g., due to demographic or precautionary saving reasons, and a decline in global investment, e.g., due to lower productivity or higher uncertainty. We also document the convergence of national interest rates: over the last few decades the explanatory power of a single global component has dramatically increased. The growing integration in international financial markets, and the related emergence of a "global cycle" may have contributed to this convergence (Miranda-Agrippino and Rey, 2015; Gerko and Rey, 2017). An implication of this phenomenon is the reduced importance of national factors to account for real interest rate movements.

Among the yields associated with the 17 countries of our sample, Swiss ones stand out as being particularly low and stable. On average over the last fifty years, nominal and real Swiss yields have been several percentage points below global averages, which confirms previous analyses (e.g., see Baltensperger and Kugler, 2017). Moreover, the volatility of Swiss yields, as measured by their standard deviations, is substantially lower than for other countries. These characteristics of Swiss bonds (low-yield/low-risk) are consistent

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with the status of safe haven of these assets (e.g., Ranaldo and Söderlind, 2010; Leutert, 2018). A trend-cycle decomposition of real interest rates confirms that low Swiss yields is a highly-persistent phenomenon: extending the analysis proposed by Del Negro et al. (2019) by including Swiss real rates, we indeed obtain that the latter have featured the lowest trend component over the last fifty years.

Under the combined effects of the fall in world rates and the convergence of national rates, very-low long-term interest rates have however become less specific to Switzerland over the last decade. More precisely, while it is still the case that nominal yields are among the very lowest in our sample, it is now less so the case for real rates. This comes from the relative low levels of inflation expectations in Switzerland. For instance, although nominal Swiss yields have been slightly lower than German ones, the position of associated real rates has been inverted over the last five years because of lower Swiss inflation expectations over this period. Interestingly, this relative position of German and Swiss real yields is consistent with the view offered by another interest rate decomposition that we conduct in our study. Using the approach originally proposed by Laubach and Williams (2003), we compute measures of monetary-policy stances, defined as the difference between effective real rates and estimates of so-called natural rate of interest (NRI). Although imprecisely estimated, these measures suggest that the monetary-policy stance is slightly more accommodating in Germany than in Switzerland.

The econometric analysis does not enable us to identify robust factors explaining the recent evolution of Swiss real rates compared to global rates. On the other hand, if we take an international arbitrage perspective, we can draw interesting lessons. The real interest rate differential is made of three elements: a risk premium for the Swiss franc, the expected real depreciation of the Swiss franc and the relative convenience yield on Swiss vs foreign government bonds. The latter can be measured as the difference in government yields after hedging exchange rate risk (through the forward market). Focusing on the difference of Swiss minus German real government bonds yields, we see that this difference turned from negative to positive in the last decade. We show that this change in sign can be explained by an increased expected depreciation of the Swiss franc and a lower convenience yield for Swiss bonds. In contrast, the risk premium in favor of the Swiss franc actually increased and cannot explain the smaller decline in real interest rates in Switzerland.

The last part of the paper focuses on the convenience yield. The analogy with the US dollar would tell us that an increase in the convenience yield should be associated with an appreciating currency, but this is not the case for the Swiss franc, as its appreciation came with a decrease in the convenience yield. We therefore re-examine the relationship between the convenience yield and the exchange rate in the Swiss context. We find that an increase in the Swiss convenience yield generates on average an appreciation of the Swiss franc, which is similar to what the literature has found for the dollar. However, this mechanism accounts for a limited share of exchange rate fluctuations and is dominated by other factors in the most recent period.

We then propose some explanations for the negative convenience yield on Swiss government bonds and for its recent decline. We examine the hypothesis that the convenience yield of the Swiss franc vis-à-vis foreign currencies results from the relative supply of and the relative demand for Swiss and foreign government bonds. We show that both the purchase of government bonds by foreign central banks and foreign exchange interventions by the SNB may have contributed to this decline by reducing the relative supply of foreign versus domestic government bonds. Interestingly, we also find that an exchange rate appreciation leads to a decline in the convenience yield, which contrasts with the previous evidence. This can be explained by the fact that an exchange rate appreciation increases the foreign currency value of Swiss government bonds, which reduces the convenience yield by making Swiss bonds less scarce. So the coexistence of an appreciating currency and a declining convenience yield could be explained by a causal link going from the exchange rate to the convenience yield, at least in the Swiss context.

The rest of the paper is organized as follows. In Section 2, we estimate inflation expectations and real interest rates. In Section 3, we analyze the evolution of global and Swiss real interest rates. In Section 4, we follow two different approaches to construct equilibrium interest rates. In Section 5, we analyze the international dimension of real interest rate differentials and, in Section 6, we focus on the convenience yield. Section 7 concludes. Appendices A to E provide modeling and estimation details. Appendix F contains additional charts and tables.

2 Measuring Real Interest Rates

In this section, we present estimates of real interest rates for seventeen countries, on a long historical sample (since the end of the 19th century), and for different maturities. Subsection 2.1 briefly defines real interest rates and Subsection 2.2 presents the methodology employed to compute real rates.

2.1 Defining the Real Rate(s) of Interest

There is no unique measure of the real interest rate. First, there are *ex-post* and *ex-ante* real interest rates. Second, on each date, there is a term structure of real interest rates: short-term real rates may differ from long-term ones. For example, denoting by $i_{t,h}$ the yield-to-maturity associated with a nominal bond of maturity h, the ex-ante real interest rate of maturity h is approximately given by:

$$r_{t,h} = i_{t,h} - \mathbb{E}_t(\pi_{t+h}), \tag{1}$$

where π_{t+h} is the annualized inflation between dates t and $t+h$. Naturally, one can also define the ex-post real interest rate $r_{t,h}^{expost}$. However, since the date-t ex-post rate of maturity h can be computed only on date $t+h$, the measurement of ex-post long-term real rates comes with a substantial lag. Hence, economic decisions taken by agents on date t do depend on ex-ante and not on ex-post real rates. Third, the real interest rate depends on the price index underlying the inflation π_t. Inflation can indeed be based on consumer/producer price indexes, on the GDP deflator; it can also exclude volatile food and energy prices (core inflation). Differences among these different inflation rates usually tend to vanish when it comes to compute their medium- to long-term expectations. In the remaining of this study, we focus on inflation rates based on consumer price indices, as this is the most widely-used concept of inflation.

2.2 Estimation Approach

For countries where governments issue inflation-indexed bonds (e.g., Treasury Inflation-Protected Securities, or TIPS, in the U.S.), real rates of different maturities ($r_{t,h}$) are readily observable on secondary sovereign-bond markets. However, inflation-indexed bonds have not been issued by many governments and not for very long.

In the absence of inflation-linked bonds, one has to rely on equation (1) to compute real rates. Nominal government yields are easily available, for any maturity and at any frequency—at least for the last three to four decades. By contrast, measures of inflation expectations are more difficult to obtain. Surveys provide such expectations, but are not available for long time periods, preventing studies on long historical samples.

In the present subsection, we develop and apply a methodology to compute long-historical samples of real interest rates, for any maturity and seventeen countries. While this approach makes use of inflation surveys to inform the estimation, it is also able to produce estimates of real rates for those dates and maturities for which survey-based inflation forecasts are not available.

2.2.1 Data

Our dataset covers a period of 150 years, from 1870 to 2020, and 17 countries: Australia, Belgium, Canada, Switzerland, Germany, Denmark, Spain, Finland, France, the UK, Italy, Japan, Netherlands, Norway, Portugal, Sweden and the USA. The earlier data comes from the database built by Jordà, Schularick, and Taylor (2015, JST hereinafter).[1] The more recent data is from Refinitiv (nominal yields) and the IMF IFS database (consumer price indices). While the JST data is at the yearly frequency, the latter is taken at the quarterly frequency. As explained below, our methodology makes it possible to eventually obtain quarterly data for our whole database (using Kalman-filter-based interpolations). Additional details are given in Table 1.

Table 1: Price indices and government bond yields

Data	Source	Start	Frequency	Maturities
Government yields	JST	$1870^{(a)}$	yearly	3 mths and 10 yrs
	Refinitiv	$1970^{(b)}$	quarterly	3 mths, 1, 2, 3, 5, 7, 10 yrs
Consumer price index	JST	$1870^{(a)}$	yearly	—
	IMF IFS	$1970^{(a)}$	quarterly	—

Note: IFS stands for "International Financial Statistics". JST refers to Jordà et al. (2015). $^{(a)}$: not for all 17 countries. $^{(b)}$: Not for all countries and maturities.

We also make use of survey-based inflation forecasts. Four sources of surveys of professional forecasters (SPF) are considered: U.S. Federal Reserve Bank of Philadephia SPF, the European Central Bank SPF, the KOF Swiss Economic Institute SPF and the one conducted by *Consensus Economics*. Additional details on surveys are given in Table 2.

2.2.2 Nominal yields

In order to compute real yields since the end of the 19th century, we need, in the first place, long historical series of nominal yields. The JST database provides us with long historical series for the 3-month and the 10-year government yields, at the annual frequency. For most countries, these series start in 1870. Yields of other maturities become available after 1970 for most countries in the Refinitiv database. For several countries, including Switzerland, that is however only in the 1990s that yields of maturities between 1 and 10 years are observed (see Table 13 in Appendix F).

[1]The JST data is available at http://www.macrohistory.net.

Table 2: Survey-Based Inflation Forecasts

Survey	Countries	Start.	Horizons	Frequency
Consensus Economics	G7 & Western Europe	1989	12 to 24 mths	M
KOF Consensus Forecasts	Switzerland	2015	5 yrs	Q
ECB SPF	Euro area	1998	5 yrs	Q
Philly Fed SPF	U.S.	2005	5 yrs	Q

Note: This table details the availability of those survey-based inflation forecasts used in our analysis. Last column: M and Q respectively stand for monthly and quarterly.

In order to obtain estimates of yields of any maturity for all dates and all countries, we build a state-space model relying on a parsimonious factor representation of each yield curve, as in Diebold and Li (2006). An advantage of this approach is that it can be used to infer yields even if part of the data is missing. Technical details are provided in Appendix A.

2.2.3 Inflation expectations

In this subsection, we present the approach pursued to get estimates of inflation expectations at all quarters between 1870Q1 to 2020Q4, for all countries and all maturities (up to 10 years).

We aim at recovering, for each date t in our sample, inflation forecasts that could have been formed by agents at the time. Introducing a subscript j to refer to a particular country, these forecasts are the $\mathbb{E}_t(\pi_{j,t+h})$ in equation (1). These forecasts—and their estimates that we will compute—have to be based only on information that is available at date t (i.e. "real-time" information). This information includes, in particular, the values of inflation preceding date t. But this information set—including only $\{\pi_t, \pi_{t-1}, \dots\}$—is arguably too narrow compared to the date-t information that is effectively used by agents to form forecasts. As a result, an approach producing estimates of (past) inflation expectations using only realized inflation data may sometimes lead to poor estimates of the forecasts agents are effectively producing. To try and address this issue, we make use of surveys of professional forecasters (SPF), when available. Intuitively, a SPF that is released on date t concentrates information that is (i) available as of date t and (ii) useful to form inflation predictions. As a result, SPF data are particularly relevant to inform our estimation of real-time inflation forecasts.[2]

Moreover, because we allow for correlations between the inflation components of the different countries, the information conveyed by the survey-based forecast of some countries is exploited for all countries. More details regarding the estimation are provided in Appendix B.[3]

Our approach results in a good fit of the consensus forecasts, as can be seen for instance for the 2-year horizon in Figure 17 (in the appendix). Unreported results, available upon

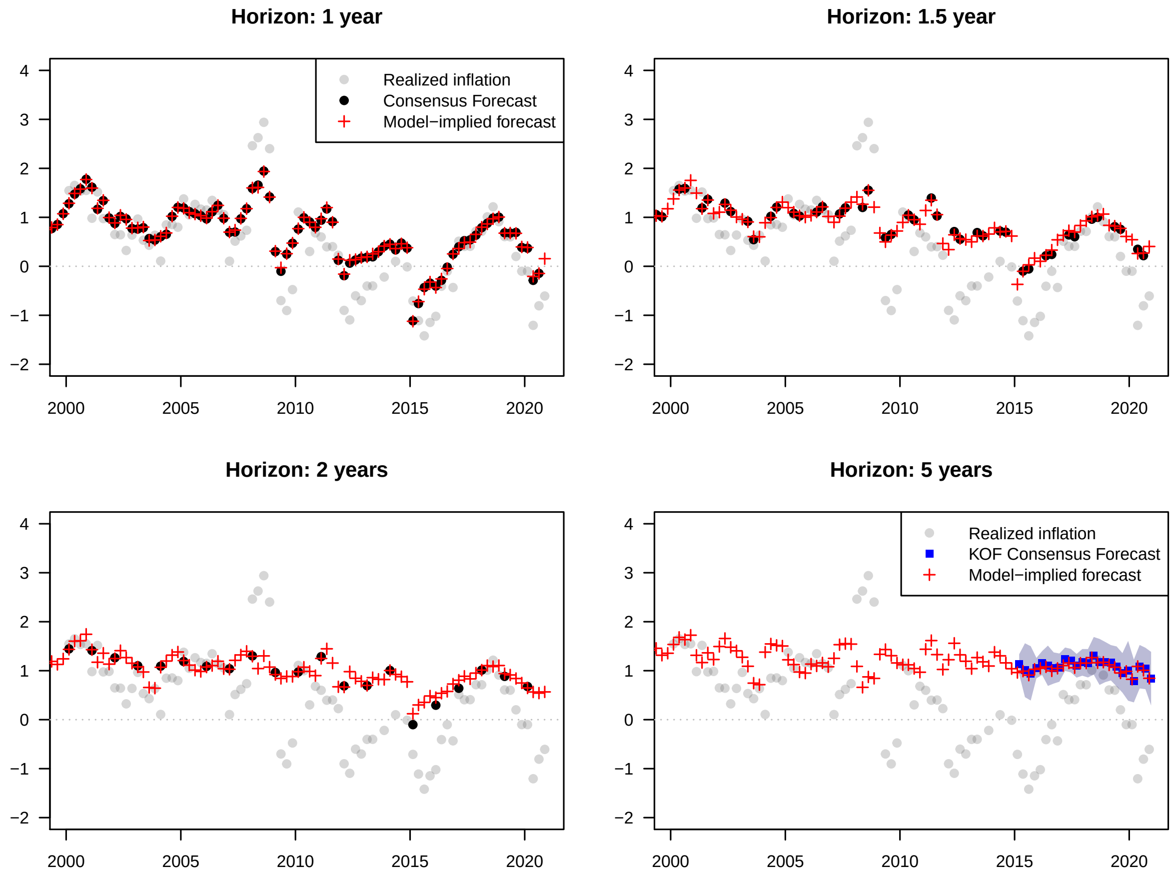
[2] Grishchenko et al. (2019) and Aruoba (2020) also exploit SPF data to recover real-time inflation expectations. The former jointly consider the euro-area and the U.S. term structures of inflation expectations; the latter focuses on the U.S. inflation expectations and uses model outputs to derive the term structure of real interest rates.

[3] Appendix B.5 also presents results obtained from a simpler approach, based on the adaptative—or error-learning—hypothesis (see e.g. Curtin, 2009, for a review of related approaches). Resulting expected inflation rates are distant from survey-based forecasts (with deviations often larger than 100 basis points), making them less reliable than those resulting from the Kalman-filter-based approach.

request, show an equivalently good fit of the surveys for the 1-year maturity.

Figure 1 focuses on the Swiss case and on a more recent period (last 20 years). This figure shows that our approach allows for a good fit of the survey up to the 5-year horizon. In order to assess the importance of incorporating forecasts in our approach, we have also computed inflation forecasts using the Kalman-filter approach described above, but without augmenting the state-space model with SPF data. Figure 18 (in Appendix F) shows that, in this case, model-implied forecasts are far from the surveys, casting doubts on the relevance of these simpler estimates.

Figure 1: Fit of survey-based forecasts (Switzerland)



This figure illustrates the fit of inflation survey-based forecasts for Switzerland. Inflation rates are expressed in percentage points. For the bottom-right plot, the grey-shaded area is the ± 1 standard deviation band around the consensus forecast reported by KOF. (The institute provides the consensus forecast as well as the standard deviations of the forecasts provided by the different forecasters; the standard deviations reflect their disagreement.)

3 The Evolution of Global and Swiss Real Interest Rates

In this Section we examine the evolution of real interest rates, with an emphasis on the more recent period. While Subsection 3.1 discusses the evolution of global rates, Subsection 3.2 focuses on the specificities of the Swiss ones.

3.1 Evolution of global rates

Global rates are measured as the averages of the 17 country-specific rates whose computation is described above. The top panel of Figure 2 shows the evolution of long-term global nominal and real interest rates over 1870-2020. The real rate is surrounded by a 95% confidence interval reflecting the uncertainty associated with the inflation-expectation filtering procedure (Subsection 2.2.3). This confidence interval is substantially reduced in the 80s, as survey-based forecasts then become available for several countries, which improves the quality of inflation expectations' estimates.

The top panel of Figure 2 clearly shows the downward effect the two world wars had on real rates. These two periods aside, the global long-term real rate appeared to have fluctuated around 3%-4% from the late 19th century to the mid 1970s. It then rose to reach 5% in the 1980s, in a context of rising inflation, and has essentially decreased since the early 1990s.

The lower panel of Figure 2 illustrates the interest rate convergence that has characterized the last decades. Conducting a principal component analysis on a 30-year rolling window, we find that the share of real rates variances accounted for by the first principal component—that can be interpreted as a global factor—increased from levels of about 50% over 1960-1990 to 85% over 1990-2020. Over the same period, the variance of the country-specific components of the yields has been divided by 5.

The real rate convergence reduces the scope for national determinants to account for recent changes in national real rates. Consistently with this idea, Rachel and Summers (2019) take the advanced economies as a bloc to explain the decreasing trend in real rates over the last forty years. According to Del Negro et al. (2019), the convergence of interest rates may reflect the growing integration in international financial markets. They also note that this finding is in line with the literature emphasizing the emergence of a "global cycle" explaining a large share of the variance in returns of risky assets around the world (e.g., Miranda-Agrippino and Rey, 2015; Gerko and Rey, 2017). According to the empirical evidence provided by Hofmann and Takáts (2015), the substantial correlation across interest rates partly reflects international monetary spillovers, i.e., a direct impact of changes in policy rates in core advanced economies on rates elsewhere, above and beyond what might be expected from other economic linkages.

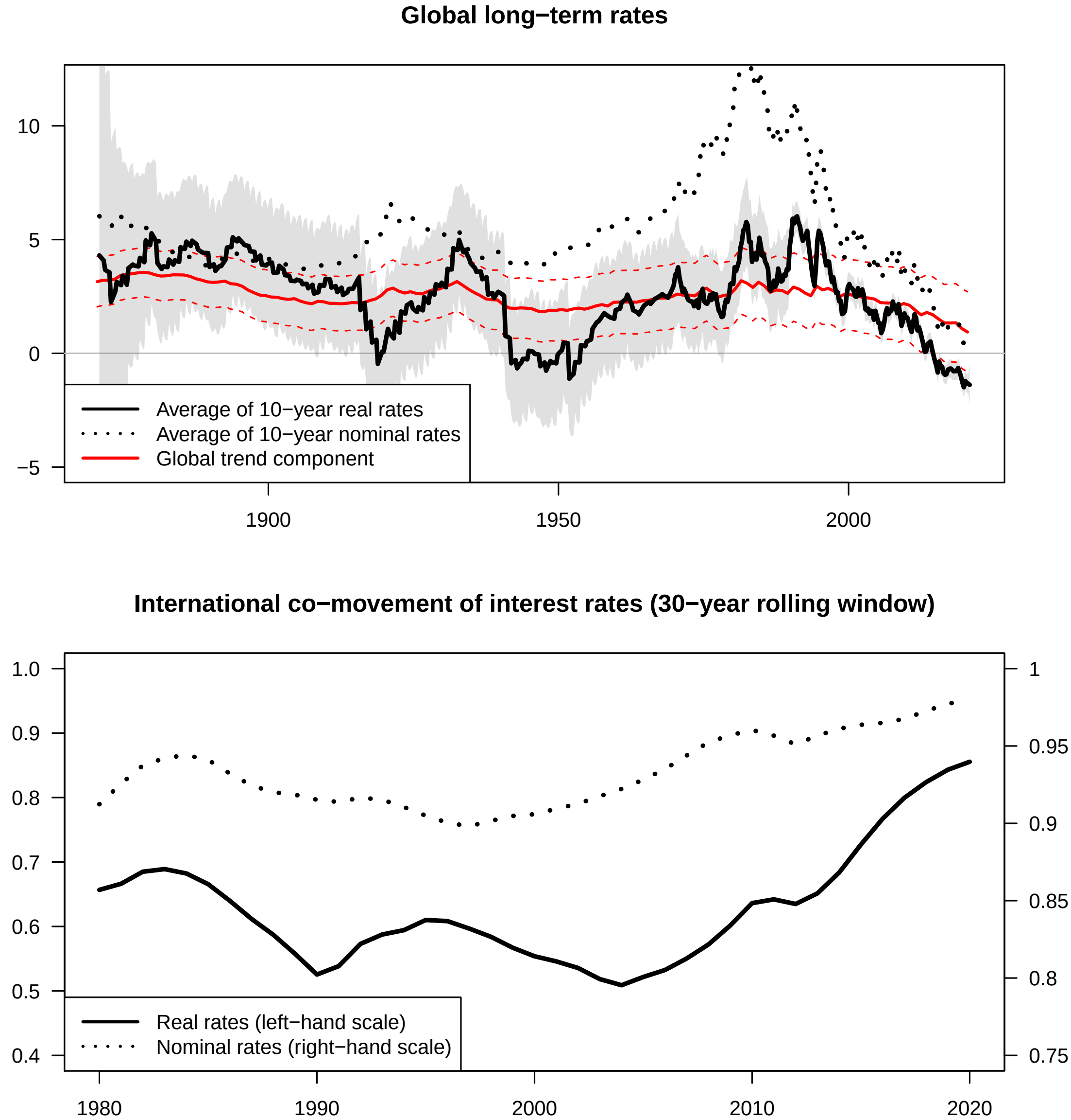
The fact that policy rates of most advanced economies have hit, or approached, the Effective Lower Bound for nominal rates has accentuated the yields compression since the global financial crisis.[4] Indeed, the volatility of long-term nominal interest rate tends to be diminished when short-term rates are constrained by the effective lower bound (see, e.g., Swanson and Williams, 2014). This reduced volatility of long-term nominal rates combined with relatively low and stable inflation expectations, has contributed to the clustering of long-term real rates around zero.

There is an expanding literature that discusses the determinants of real interest rates and that provides explanations for the decline in the global rate.[5] These well-known explanations point to an increase in global saving, e.g., due to demographic or precau-

[4]If storage costs of cash were zero, the lower bound for nominal yields would be zero (that is the return on cash). The fact that various policy rates have reached the negative territory demonstrates the existence of non-null cash storage costs. Accordingly, the expression "Zero Lower Bound" (ZLB) has been replaced by "Effective Lower Bound" (ELB).

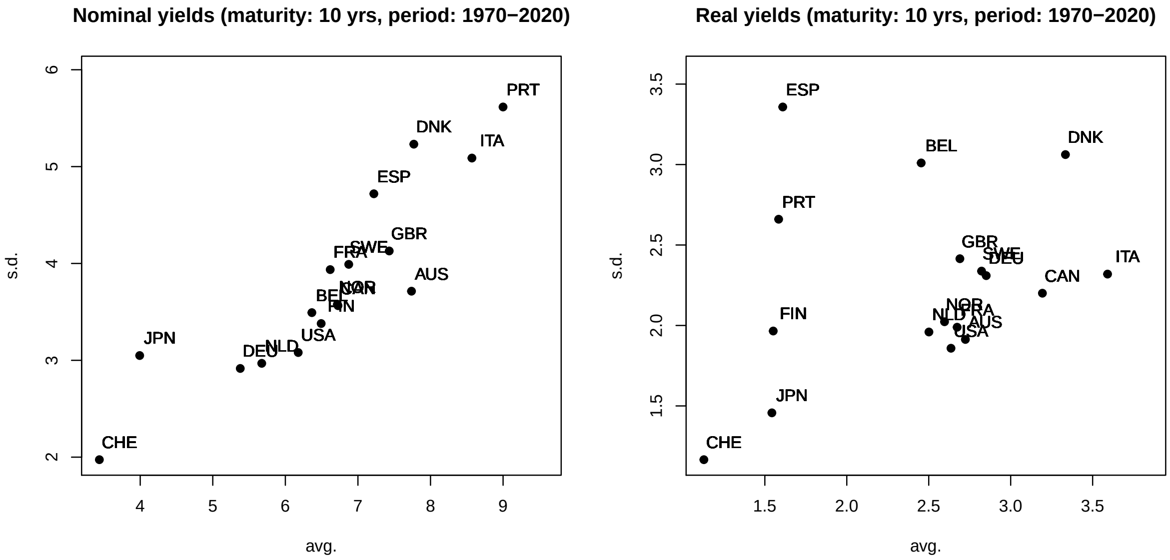
[5]E.g., see Rachel and Smith (2015); Hördahl et al. (2016); Demary and Voigtländer (2018); Rachel and Summers (2019). Lunsford and West (2019) focus on the US real rate. Some of the empirical analyses use measures of equilibrium real interest rates that we describe below.

Figure 2: Long-term global interest rates, average level and convergence measure



The upper panel shows the average, across the 17 countries of the JST database, of the 10-year nominal and real interest rates (in percentage points). The red line corresponds to the global trend of long-term rates resulting from the approach proposed by Del Negro et al. (2019) (see Subsection 4.1). The lower panel illustrates the convergence of international interest rates. It displays the (time-varying) share of variances accounted for by the first principal component of the 17 interest rates, for both real and nominal interest rates. The principal component analysis is conducted over a 30-year rolling window. For instance, for 2020, it shows the share of the variances of the 17 (real or nominal) interest rates accounted for by the first principal component over 1990-2020.

Figure 3: Means and variances



x-coordinates correspond to the average interest rates over the period; y-coordinates give the standard deviation of the interest rates. Yields are expressed in percentage points.

tionary saving reasons, and a decline in global investment, e.g., due to lower productivity or higher uncertainty. There may also be an increase in the demand for safe assets putting downward pressure on government yields (see Caballero et al., 2016; Glick, 2020). We should note, however, that it is difficult to identify factors that can significantly explain real interest rates over long horizon. For example, estimated coefficients are not robust in panel regression analyses (see Borio et al., 2019, for a discussion).

3.2 The relative evolution of Swiss yields

In this subsection, we discuss the relative situation of Swiss real and nominal rates within the group of 17 countries of the Jordà et al. (2015) database. We focus our discussion on the 10-year maturity, the observations being qualitatively similar for other maturities. (Figures and tables pertaining to other maturities can be found in Appendix F.)

Overall, Swiss yields are particularly low and are less volatile than in the other countries of the sample. This is documented for the 10-year maturity in Table 3, which displays descriptive statistics of interest rates for: 1880-2020, 1880-1970 and 1970-2020.[6] For the three periods, the Swiss nominal yields are the lowest on average. Regarding the real yields, that is only when we consider the last 50 years that the Swiss yields are the lowest, with an average of 1.1%. The next two countries are Finland and Japan, with average 10-year real rates of 1.5%. For all considered periods, Swiss real and nominal yields present the lowest volatility, as measured by standard deviations.

[6]See Tables 14 and 15 (in Appendix F) for the 2-year and 5-year maturities, respectively. Figures 20 and 21 respectively display the decomposition of the 2-year and 10-year nominal rates into real rates and inflation expectations for the 17 countries of the Jordà et al. (2015) database.

Table 3: Descriptive statistics of 10-year yields

		CHE	AUS	BEL	CAN	DEU	DNK	ESP	FIN	FRA	GBR	ITA	JPN	NLD	NOR	PRT	SWE	USA
Nominal yields, 10-year maturity																		
1880-2020	avg.	**3.6**	5.4	4.9	4.9	5.2	5.7	5.8	7.0	5.2	5.0	6.7	5.2	4.4	5.0	7.1	5.1	4.4
	s.d.	**1.3**	2.9	2.5	2.6	2.1	3.6	3.3	3.3	2.8	3.2	3.3	2.2	2.1	2.5	4.4	2.8	2.3
	vol.	**18.7**	31.3	25.6	29.5	29.6	32.5	36.0	33.9	28.2	32.3	42.1	28.7	24.8	24.4	43.9	29.2	37.3
	IQ	**1.3**	2.4	2.6	2.4	2.8	2.3	1.6	5.0	3.3	3.0	1.6	2.2	2.0	2.1	5.9	2.2	1.8
1880-1970	avg.	**3.8**	4.2	4.1	3.9	5.1	4.6	5.1	7.4	4.5	3.8	5.7	5.8	3.8	4.1	6.1	4.1	3.5
	s.d.	**0.7**	0.9	1.1	1.0	1.5	1.2	1.8	3.3	1.4	1.3	0.7	1.2	0.9	0.9	3.1	0.9	0.8
	vol.	**8.4**	9.8	10.5	8.4	15.6	9.0	18.5	26.7	10.5	8.7	12.5	21.9	8.5	9.2	28.4	7.4	10.5
	IQ	**0.9**	1.5	1.7	1.6	2.5	1.4	0.9	4.9	2.7	1.6	1.2	1.5	0.9	1.4	4.1	0.9	0.9
1970-2020	avg.	**3.4**	7.7	6.3	6.7	5.3	7.7	7.2	6.4	6.6	7.4	8.5	3.9	5.6	6.7	8.9	6.8	6.1
	s.d.	**1.9**	3.7	3.4	3.5	2.9	5.2	4.7	3.3	3.9	4.1	5.0	3.0	2.9	3.5	5.6	3.9	3.0
	vol.	**29.1**	50.6	40.1	47.9	44.8	52.7	54.7	43.6	44.8	52.5	68.5	37.7	39.7	38.8	62.6	47.7	60.9
	IQ	**2.7**	4.7	4.6	5.2	4.2	7.2	7.7	5.7	5.6	6.4	8.5	5.5	4.3	5.0	10.1	6.5	4.2
Real yields, 10-year maturity																		
1880-2020	avg.	**1.7**	2.6	2.0	2.5	3.4	2.7	1.7	3.3	1.5	2.2	3.1	2.2	2.0	2.3	2.9	2.4	2.7
	s.d.	**1.4**	1.8	2.4	1.7	1.8	2.4	3.9	2.5	2.5	1.8	2.1	2.2	2.0	2.0	3.4	2.0	2.4
	vol.	**30.9**	40.3	43.8	40.5	36.9	42.2	49.3	48.9	42.6	43.5	51.8	47.4	36.9	40.3	54.4	40.3	45.8
	IQ	**1.8**	2.5	3.4	1.9	1.4	3.1	5.4	3.1	3.5	2.1	2.5	2.2	3.1	3.0	3.9	2.7	3.3
1880-1970	avg.	**2.1**	2.6	1.7	2.2	3.8	2.5	1.7	4.2	0.9	2.0	2.9	2.5	1.8	2.2	3.6	2.2	2.8
	s.d.	**1.3**	1.8	2.0	1.4	1.4	2.0	4.2	2.3	2.6	1.4	2.0	2.5	2.1	2.0	3.6	1.8	2.7
	vol.	**32.2**	34.9	41.1	30.9	31.6	37.8	43.1	51.5	40.6	30.1	39.8	49.4	35.1	38.0	48.6	36.3	36.1
	IQ	**1.7**	2.6	3.2	1.4	1.2	2.3	6.3	2.4	3.7	2.3	2.7	3.1	3.7	2.8	3.8	2.9	4.4
1970-2020	avg.	**1.1**	2.7	2.4	3.1	2.8	3.3	1.6	1.5	2.6	2.6	3.5	1.5	2.5	2.5	1.5	2.8	2.6
	s.d.	**1.1**	1.9	3.0	2.2	2.3	3.0	3.3	1.9	1.9	2.4	2.3	1.4	1.9	2.0	2.6	2.3	1.8
	vol.	**28.5**	48.5	48.2	53.5	45.0	49.0	58.5	43.6	46.0	60.5	68.3	43.6	39.8	44.8	63.4	46.8	59.7
	IQ	**1.1**	2.2	4.8	2.9	2.6	4.1	3.7	2.0	2.0	2.1	2.0	1.4	2.0	3.4	3.1	2.8	1.9

Note: This table reports descriptive statistics for 10-year yields. “avg.” stands for “average”; “s.d.” stands for “standard deviation”; “vol.” stands for “volatility”, it is defined as the standard deviation of the changes in the interest rates, expressed in basis points; “IQ” stands for “inter-quartile”, i.e. the difference between the 75th and the 25th quantiles. CHE: Switzerland, AUS: Australia, BEL: Belgium, CAN: Canada, DEU: Germany, DNK: Denmark, ESP: Spain, FIN: Finland, FRA: France, GBR: U.K., ITA: Italy, JPN: Japan, NLD: Netherlands, NOR: Norway, PRT: Portugal, SWE: Sweden, USA: United States of America.

Figure 3 highlights the specificities of Swiss yields. This figure indeed plots yields' standard deviations against averages over the last 50 years. Swiss yields being low and not volatile, Switzerland appears in the lower left corner of the plots. More generally, the plots show the positive relationship between returns average and volatility, which is consistent with basic mean-variance reasoning (investors are willing to get lower returns if asset prices are less volatile).[7]

Figure 4 allows to assess the relative position of Swiss yields through time, considering the breakdown of nominal yields into their real yield component and inflation expectations. The different plots of this figure compare the Swiss yields and expectations (black solid lines) to Germany (light blue), Japan (light red) and the 14 other countries (grey circles). It appears, in particular, that while nominal German yields were at least 100 bp above Swiss ones between 1980 and 2010, this spread has almost vanished. Moreover, because German inflation expectations are now substantially higher than Swiss ones,[8] German real rates have been evolving slightly below Swiss ones for more than five years now.

An important question is whether we can identify factors specific to Switzerland that can explain the recent decline in real yields. To examine this question we applied a standard regression analysis, either in a panel for the 17 countries in our sample or for Switzerland only. Following the literature, we included a set of variables affecting saving and investment.[9] The results of such an analysis are basically inconclusive. First, and similarly to the analyses of the global interest rate, the variables are often insignificant and the regression results are not robust to changes in sample length and specifications.[10] Second, even in the specifications with significant variables, the decline in real interest rates cannot be explained by country-specific variables (see Kiley (2019) for similar results).

The variable that is most significantly associated with the recent decline in the Swiss real rate is the global real rate.[11] This is illustrated in Figure 5. It shows the evolution of the Swiss 10-year real interest rate, as well as the fitted values derived from two panel regressions with a 95% confidence interval. The first regression only includes country-specific variables, while the second regression also includes the global (GDP-weigthed) real interest rate. These regressions are presented in Table 10 in the Appendix. The fitted value of the regression including the global interest rate is closely in line with the actual interest rate, even showing a larger decline. In contrast, the fitted value without the global rate is unable to capture the recent decline. This result is consistent with the previous analysis that shows the growing co-movement in real interest rate and confirms that movements in the Swiss real rate are dominated by the global rate.

4 Measures of Equilibrium Long-Term Real Rates

The previous section has shown that nominal and real Swiss yields are among the lowest and most stable. We have also illustrated (i) the decline in interest rates that has

[7]Note that this simple analysis does not account for exchange rate effects; the latter aspects will be discussed more deeply in Section 5.

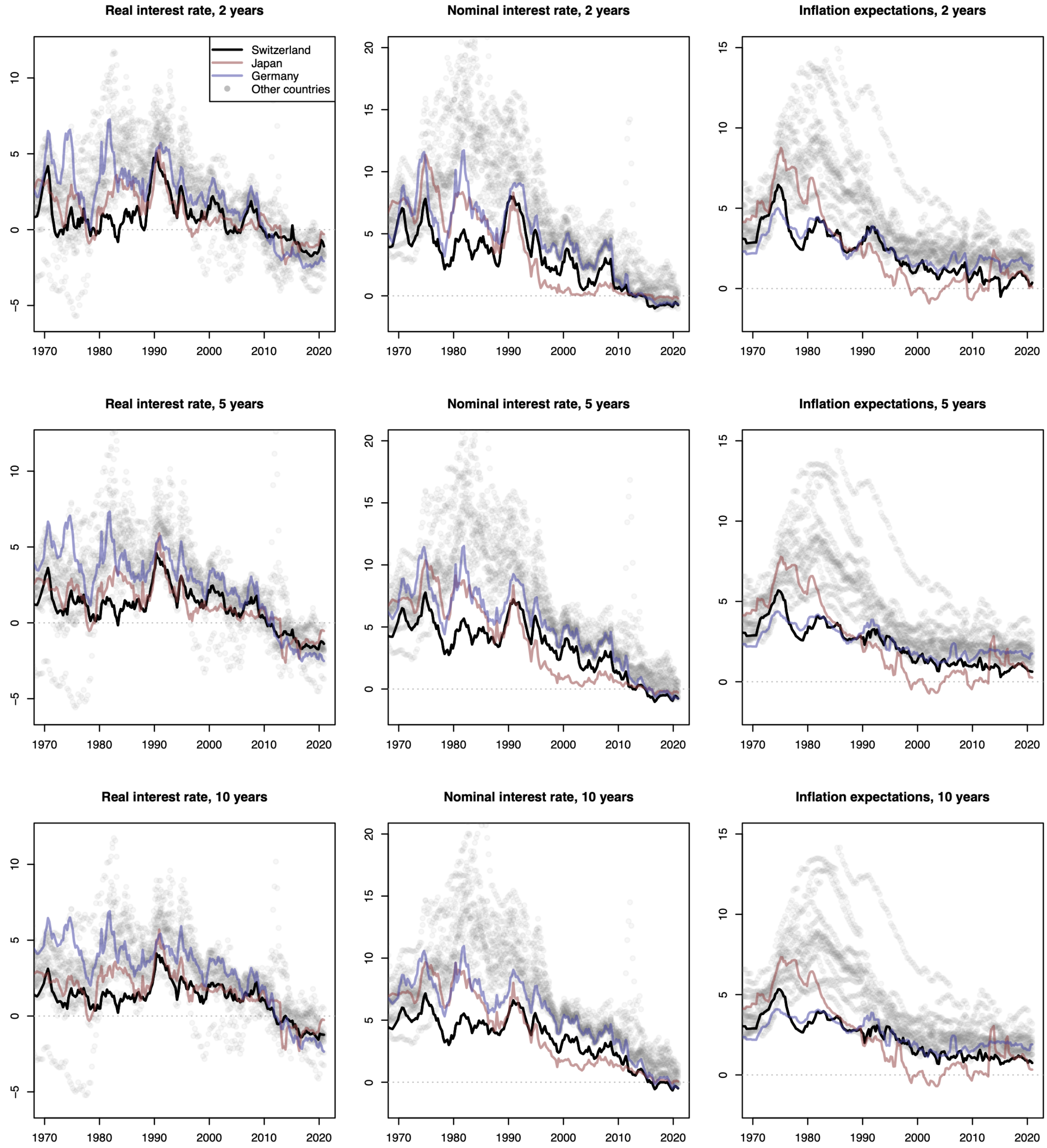
[8]In 2020Q4, the 5-year inflation expectations for Switzerland and the euro area were respectively of 0.84% and 1.66%, according to the KOF consensus forecast and the ECB survey of professional forecasters.

[9]The variables considered include life expectancy, the dependence ratio, the share of the top ten percent income, GDP growth, the investment rate, government consumption, inflation, or government debt.

[10]We ran regressions with a very long sample, starting in 1890, with a limited number of explanatory variables, as well as short samples with more variables.

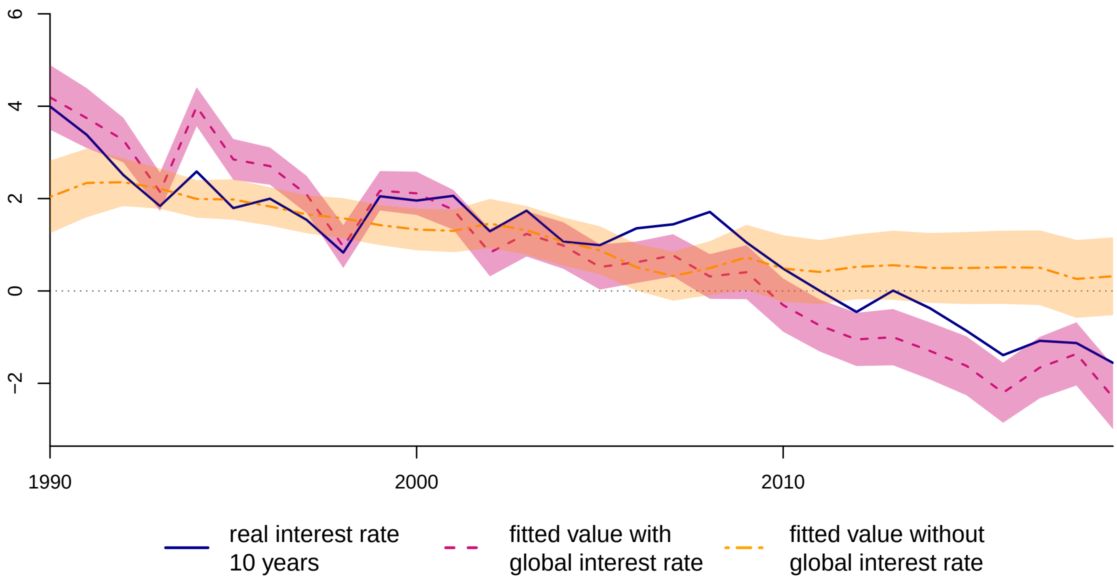
[11]Kiley (2019) also shows that global variables are predominant in a panel regression.

Figure 4: Interest rate decompositions



This figure shows the decomposition of nominal rates (2nd column of plots) into a real rate component (1st column of plot) and inflation expectations (3rd column of plots). Interest and inflation rates are expressed in percentage points. The computation of inflation expectations is detailed in Subsection 2.2.3. The blue and red lines respectively correspond to Germany and Japan. The grey dots correspond to the other 14 countries of the Jordà et al. (2015) database.

Figure 5: 10-Year Swiss Real Interest Rate: Actual and Fitted Values



The fitted values and their 95% confidence interval are computed from the regressions in Table 10. Interest rates are in percentage points.

taken place in recent decades, as well as (ii) the concomitant rates' convergence. An important question concerns the persistence, or structural nature, of these phenomena. In other words, are these movements driven by the trend, or natural, components of interest rates? Or are they more cyclical? In order to address these joint questions, this section considers two notions of such "equilibrium interest rates". This first measure is proposed by Del Negro et al. (2019). This measure is based on the estimation of the low-frequency components of nominal interest rates and inflation; subtracting these two components provides, in turn, the real rate trend. The second measure of equilibrium interest rates considered in this section relates to monetary policy. It is the so-called Natural Rate of Interest (NRI), defined as the value of the real rate that would be consistent with stable inflation (Laubach and Williams, 2003).

4.1 Del Negro et al.

Del Negro et al. (2019) propose an econometric framework to estimate the secular trends of real interest rate. The approach consists in looking for a set of trends—i.e., non-stationary, or infinitely persistent components—that account for the low frequency movements of short and long nominal interest rates, and inflation. Del Negro et al. (2019) focus on seven countries: Canada, France, Germany, Italy, Japan, the UK and the US. We augment this set of countries with Switzerland and employ a broadly similar approach.

The estimation relies on the following decomposition of the short-term and long-term nominal yields:

$$i_{j,t,3mth} - \pi_{j,t} = \overline{r}_t^w + \overline{r}_t^i + c_{j,t} \quad (2)$$

$$i_{j,t,10yr} - \pi_{j,t} = \overline{r}_t^w + \overline{r}_t^i + \overline{ts}_t^w + \overline{ts}_t^i + d_{j,t} \quad (3)$$

$$\pi_{j,t} = \overline{\pi}_t^w + \overline{\pi}_t^i + e_{j,t}, \quad (4)$$

where overlined variables are random walks, or trends, and the variables with a w superscript are global components. Specifically: $\overline{r}_t^w$ is the trend in the short-term world real interest rate, $\overline{\pi}_t^w$ is the global inflation trend, and $\overline{ts}_t^w$ is the global term spread (i.e. the trend of the slope of the global real yield curve). The $\overline{r}_t^i$'s and $\overline{\pi}_t^i$'s are country-specific real rate and inflation trend components, respectively. The remaining variables, $c_{j,t}$, $d_{j,t}$ and $e_{j,t}$, are country-specific stationary components that follow autoregressive processes. All rates and inflation components (those appearing on the right-hand side of eqs. 2, 3 and 4) are latent and are estimated by Kalman filtering techniques.[12]

In this framework, the trends in the short-term and the long-term real rates are respectively given by:

$$\overline{r}_{i,t} = \overline{r}_t^w + \overline{r}_t^i \tag{5}$$
$$\overline{R}_{i,t} = \overline{r}_t^w + \overline{ts}_t^w + \overline{r}_t^i + \overline{ts}_t^i, \tag{6}$$

where $\overline{r}_t^w + \overline{ts}_t^w$ is the trend of the global long-term real rate.

Figure 6 shows the time series of the estimated trends of the national short-term real rates (the $\overline{r}_{i,t}$'s). The grey areas are 95% confidence intervals for the global trends of real interest rate (short-term rate for the top panel, long-term rate for the bottom panel). The fact that the national interest rates are essentially within this confidence intervals indicates that it is difficult for the methodology to precisely estimate national trend components (the $\overline{r}_t^i$'s in eq. 5). The uncertainty surrounding national trend estimates is further illustrated on Figure 7, that also reports 95% confidence intervals. This high level of uncertainty results from the fact that even the stationary components of interest and inflation rates ($c_{j,t}$, $d_{j,t}$ and $e_{j,t}$) are also persistent: the more persistent the cyclical components are, the more difficult it is for the filter to distinguish them from trends. This high persistence may reflect the effects of some macro-finance phenomena whose effects eventually subside, but that can have long-lasting effects. Such long-lasting phenomena may include private sector leveraging/deleveraging, or changes in the investors' perception of tail risks (related to the debt cycle argument of Rogoff, 2016, see also Borio et al., 2019). A consequence of the difficult identification of the trends is that confidence intervals around the national trend estimates strongly overlap (Figure 7). In other words, from a statistical viewpoint, the approach does not identify important difference among national real-rate trends.[13]

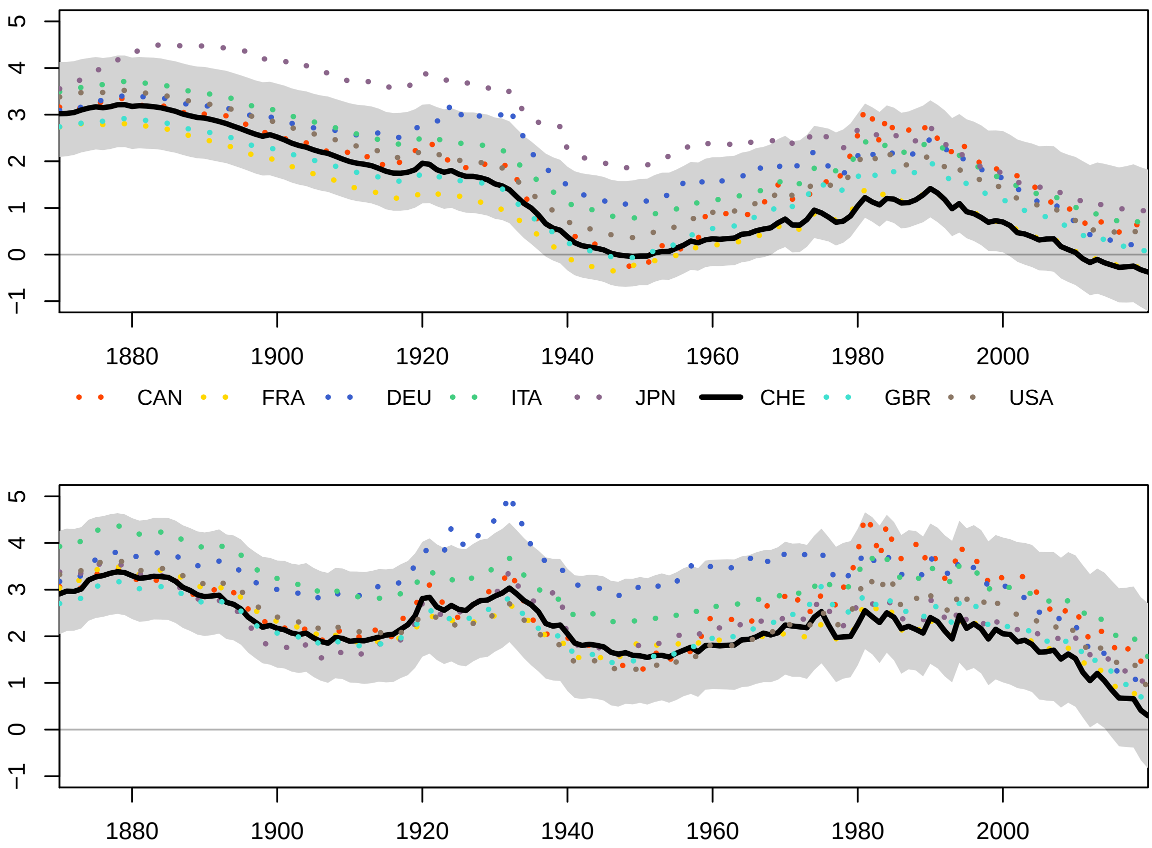
Notwithstanding these caveats, let us compare national trend rates. First, it appears on Figure 6 that the Swiss real rate trends (black solid line) have been the lowest in the last forty to fifty years. This is true for both the short-term real rate (top panel) and the long-term rates (bottom panel). Second, we also observe some forms of convergence in the trends over the last 40 years, although this is less marked than for the yields themselves (Subsection 3.1). Third, Figure 6 shows that interest rate trends have declined by about 200 basis points over the last forty years, accounting for a substantial part of the decrease in real rates (see Subsection 4). Because both the estimated trends and stationary real-rate components are highly persistent processes, these results tend to predict a protracted period of low real interest rates worldwide.[14]

[12] Contrary to Del Negro et al. (2019) (who use Bayesian techniques), our state-space model is estimated by maximum likelihood. We employ the Kalman filter to calculate the likelihood function. The initialization of the Kalman filter is based on the priors used by Del Negro et al. (2019).

[13] Note that this result is not specific to our replication, the same holds true for the original results of Del Negro et al. (2019).

[14] Nevertheless, the uncertainty associated with model-based forecasts of the real rates is substantial.

Figure 6: Estimated trends of countries' real rates



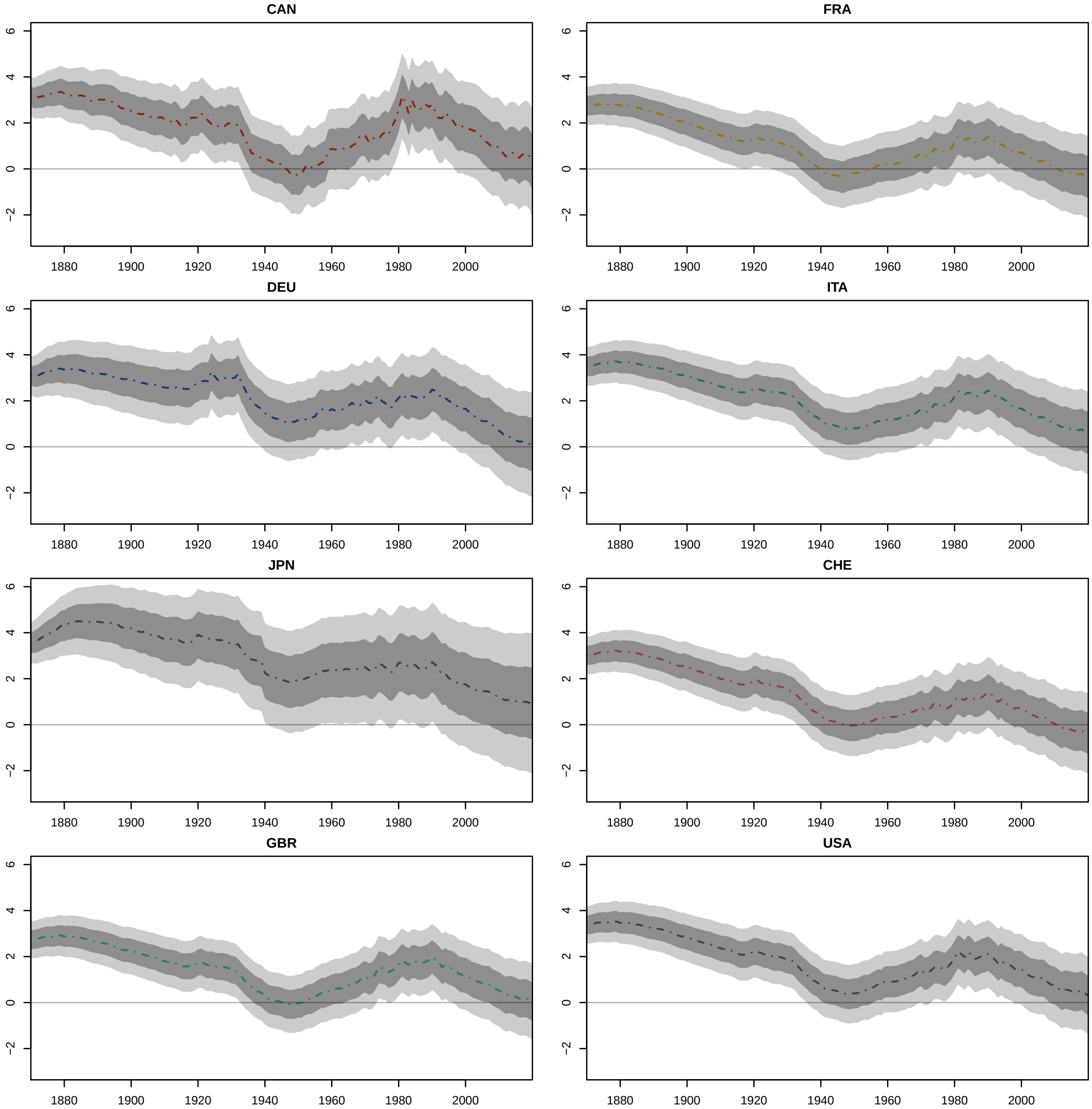
This figure displays the estimates of $\bar{r}_{i,t}$ (top panel) and of $\overline{R}_{i,t}$ (bottom panel), see eqs. (5) and (6). Interest rates are expressed in percentage points. These are the trends in the national real short-term real rates and long-term real rates, respectively. The estimation approach is based on Del Negro et al. (2019). Grey areas are 95% confidence intervals for the trends of the world short-term real rate, i.e. $\bar{r}_t^w$ (top panel) and of the world long-term real rate trend, i.e. $\bar{r}_t^w + \overline{ts}_t^w$ (bottom panel).

4.2 Natural Rates of Interest

In this subsection, we consider a second type of equilibrium interest rate, namely the natural rate of interest (NRI). The NRI can also be seen as a low frequency component of real rates, but, contrary to the trend measures derived in the previous subsection (4.1), the estimation of the NRI is usually based on small-scale models involving monetary policy. While the NRI concept dates back to the late 19th century, it has enjoyed a renaissance within academic, practitioner and central-bank circles over the last two decades. The NRI was defined by Wicksell (1898) in the following way: "*There is a certain rate of interest on loans which is neutral in respect to commodity prices, and tends neither to raise nor to lower them.*" Interestingly, as will be detailed below, recent NRI estimation are still directly based on the previous definition (although they tend to focus on consumer rather than commodity prices).

The NRI is useful in providing a yardstick for assessing the expansionary or restrictive tendency of real interest rates at any given time (Amato, 2005). More precisely, the monetary-policy stance can be measured by the interest rate gap (IRG), that is the difference between the effective real rate and the NRI. By definition of the NRI, it indeed comes that a positive (negative) IRG indicates a contractionary (expansionary) monetary-policy

Figure 7: Estimated trends of countries' real rates



This figure displays the estimates of $\overline{r}_t^i$, that are the trends in the national real rates. The estimation approach is based on Del Negro et al. (2019). The shaded areas show the 68 and 95 percent confidence intervals, which capture the filtering uncertainty. Interest rates are expressed in percentage points.

stance. In other words, the IRG can be seen as a yardstick to measure the short- to medium-run influence of the central bank on real rates.

A widely-used approach to estimate NRIs is the one proposed by Laubach and Williams (2003).[15] It relies on a small reduced-form macroeconomic model featuring essentially a Phillips curve and an IS curve. While the former relates inflation to the output gap, the latter relates the output gap to the IRG. Laubach and Williams (2003)'s model parsimoniously captures the fact that when monetary policy is accommodative, then the output gap and, further, inflation are under upward pressure. This mechanism is then exploited

[15] Studies using this approach include Mésonnier and Renne (2007) for the euro area, Holston et al. (2017) for the US, the UK, Canada and the euro area, and Fries et al. (2016) for France, Germany, Italy and Spain.

to infer the level of the NRI. Heuristically, a period of sustained increase in output growth and inflation is suggestive of a negative interest rate gap. The NRI is finally obtained as $r_t - IRG_t$, where r_t is a real rate.

Laubach and Williams (2003) impose additional constraints to facilitate the NRI estimation. Namely, part of the NRI fluctuations are assumed to comove with the trend in the potential GDP growth rate. The second component of the NRI is assumed to reflect shifts in the rate of time preference. The two NRI components—potential GDP growth trend and rate of time preference—are modelled as extremely persistent processes (as were the trends in the approach of Subsection 4.1). The model is put in a state-space form and the Kalman filter is used to estimate the different latent factors, as described in Appendix D. This Appendix also contains figures showing the 17 estimated NRIs (Figure 15) and the associated output gaps (Figure 16).

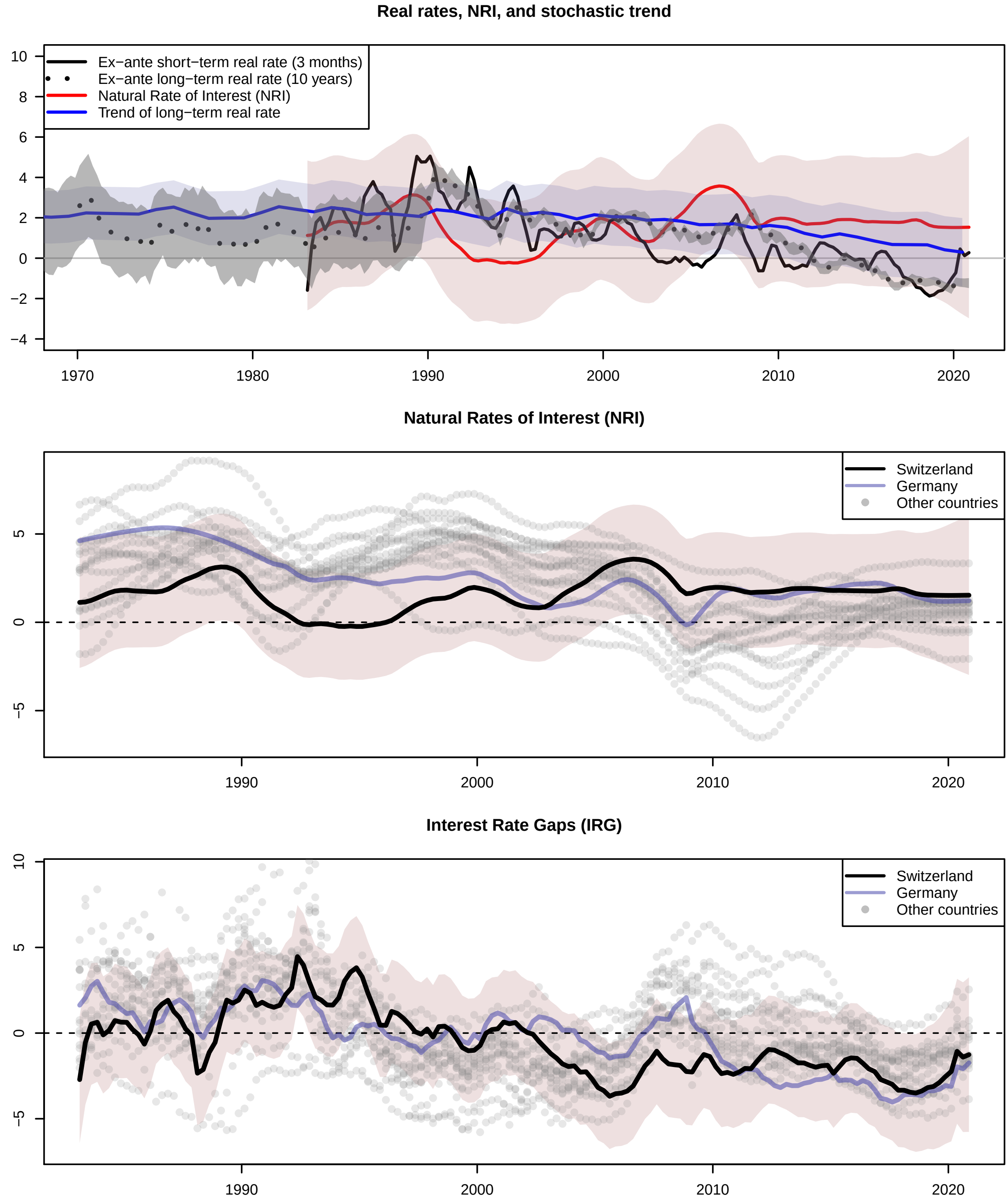
The upper panel of Figure 8 displays the Swiss Natural Rate of Interest (NRI), in red. We find that the Swiss NRI has fluctuated between 0% and 3% over the last forty years. It would be stable and close to 2% since 2010. Our computations reveal a substantial level of uncertainty surrounding the NRI estimates: except for a few years (late 80s and late 2000s), zero has lain in the 90% confidence intervals since the early 80s. This lack of precision is in line with alternative NRI estimations (e.g. Brand et al., 2018; Holston et al., 2017; Rachel and Summers, 2019; Kiley, 2020). As argued by Fiorentini et al. (2018) and Borio et al. (2019), this may be due to the fact that the IS curve or the Phillips curve is flat: because the NRI is essentially identified through the estimated effect of the interest rate gap on inflation, if either the IS or the Phillips curve is flat, the natural rate of interest is only weakly identified.[16]

For the sake of comparison, we also report the trend rate resulting from the Del Negro et al. (2019) approach (Subsection 4.1) in the upper panel of Figure 8. The latter seem to be less volatile than the NRI estimate. Nevertheless, the fact that the two associated confidence intervals largely overlap implies that care should be taken in interpreting these differences.

The second panel of Figure 8 compares the 17 NRIs. The Swiss NRI has been more stable than in other countries; while it was among the lowest in the 80s and 90s, it has become one of the highest over the last 20 years. The Swiss NRI appears to have been at par with the German one over the last decade. Fiorentini et al. (2018) also estimate that the Swiss NRI has been stable and close to zero since 2000 (see their Figures 19 and 21). The middle panel of Figure 8 further suggests that, on average across countries, the NRIs have declined in the 2000s, from about 3% in 2000 to 1% in 2020. This is broadly consistent with the literature. Holston et al. (2017) highlight the role of the slowdown in the trend productivity growth to account for this decline. Fiorentini et al. (2018) find that changing demographic composition explains the bulk of the evolution of their NRI estimates. They further find some evidence for a risk channel: higher risk may have driven the natural rate down by increasing the propensity of the households to save. Brand et al. (2018) also argue that risk aversion and flight to safety have contributed to the temporary NRI decline in the wake of the global financial crisis; Krustev (2019) relate this temporary decline to financial deleveraging.

[16]The IS curve captures the effect of the interest rate gap—the difference between the observed interest rate and the NRI—on the (latent) output gap, and the Phillips curve captures the effect of the latter on inflation. Our estimate of the IS curve (a_r in Table 11) is not statistically significant. The estimated slope of the Phillips curve (b_z in Table 11) is statistically significant at the 10% level, but economically small.

Figure 8: Swiss Natural Rate of Interest (NRI) and Interest Rate Gap (IRG)



The upper panel shows two measures of equilibrium real rates of interest for Switzerland: the trend in the long-term real rate resulting from the Del Negro et al. (2019) approach (Subsection 4.1) and the Natural Rate of Interest (NRI) whose estimation is based on an approach *à la* Laubach and Williams (2003). Shaded areas are 90% confidence intervals (shown for Swiss estimates only). Regarding the ex-ante long-term real rate (dotted line), the confidence interval reflects uncertainty surrounding inflation expectation estimates (Subsection 2.2.3); this uncertainty decreases in the 80s because the estimation then starts to benefit from the availability of survey-based forecasts. The black solid line corresponds to the short-term real rate computed as a by-product of the NRI estimation approach. **The middle panel** shows estimated NRIs for the 17 countries of the Jordà et al. (2015)'s database. **The bottom panel** shows interest rate gaps (IRGs); for each of the 17 countries, the IRG is measured as the difference between the ex-ante short-term real rate and the NRI. A positive (respectively negative) IRG indicates a tight (accommodative) monetary-policy stance. Interest rates are expressed in percentage points.

Let us now exploit our NRI estimates to discuss monetary policy stances. As said above, these stances can be measured by IRGs, calculated as the difference between the effective real rate and the NRI. Usually, the real interest rate involved in this computation is a short-term one; the short-term Swiss real rate is displayed in black in the upper panel of Figure 8. For comparison, this panel also displays the long-term real rates resulting from Section 2 (dotted line). Since the two real rates (short and long) share the same low-frequency fluctuations, it appears that the sign of the IRG would be fairly robust to the choice of the real rate's maturity.[17] The IRG based on the short-term real rate—the one usually considered in the literature—is shown on the lower panel of Figure 8. The fact that the IRG is negative since the early 2000s indicates an accommodative monetary-policy stance; according to the 90% confidence interval, it was however statistically significant only in the mid 2000s and in 2018. The grey dots show the IRGs of the other countries, except for Germany, whose IRG is plotted in blue. The results therefore suggest that the monetary-policy stance has been accommodative in most considered countries over the last few years. It also appears that whereas the Swiss monetary policy has been among the most accommodative, the German stance has been slightly more so.

Our IRG estimates appear to be highly persistent.[18] Assuming that this persistency will last, one can envision a slow return of real rates to their natural level in the short- to medium-term. As for the trend itself (the NRI), the present framework mechanically predicts an (average) stable trajectory. This is in line with the finding of Brand et al. (2018): investigating the predicted trajectories underlying different NRI estimation approaches, these authors find overall evidence for NRIs staying at levels around zero (rather than rebounding) in the coming years.

5 Real Interest Rates and International Arbitrage

The previous sections have shown that Swiss real interest rates have decreased less than in many other countries and are even currently higher than German rates (see Figure 4). Does this mean that Swiss franc bonds have become less attractive so that Swiss bonds have to offer higher yields than German bonds? To answer this question, we need to examine the relevant arbitrage conditions and take into account the fact that interest rates are measured in different currencies. We also make explicit the difference between government yields and risk-free yields. This will give a finer analysis of interest rate differentials, especially in the shorter run.

For notational convenience, we focus on the differential between two countries, Home and Foreign. Denote $r_{t,h}$ and $r^*_{t,h}$ the Home and Foreign country real yields on government bonds. All Foreign country variables have a * superscript. We also consider risk-free yields (guaranteed by collateral) for Home and Foreign $i^s_{t,h}$ and $i^{s,*}_{t,h}$. Moreover, let define the nominal depreciation rate of the Home currency versus the Foreign currency as $\Delta s_{t+h} = s_{t+h} - s_t$, where s_t is the log nominal exchange rate, and the real depreciation rate as $\Delta q_{t+h} = q_{t+h} - q_t$, where q_t is the log real exchange rate. Notice that $\Delta q_{t+h} = \Delta s_{t+h} +$

[17] The maturity of the NRI is not discussed in the literature. As the NRI is modelled as a sum of random walks, it comes that its forecast, at any horizon, is equal to its current value. As a result, under the expectation hypothesis, and in the "natural" environment (where only permanent output shocks and preference shocks apply), the term structure of interest rates would be flat at the current NRI level.

[18] Note that the estimation approach does not necessitate assumptions regarding the persistence of the IRG. The cross-country average of the sample autocorrelations of the IRGs is of 0.96, which is suggestive of a strong persistency.

$\pi^*_{t+h} - \pi_{t+h}$. It is also useful to define the excess return in foreign currency, or the risk premium, as: $xs_{t+h} = \Delta s_{t+h} + i^{s,*}_{t,h} - i^s_{t,h}$.

The Home country convenience yield can be measured by the differential in yields between the risk-free asset and government bonds: $i^s_{t,h} - i_{t,h}$. The relative convenience yield between Home and Foreign is therefore defined as:

$$\lambda_{t,h} = (i^s_{t,h} - i_{t,h}) - (i^{s,*}_{t,h} - i^*_{t,h}). \tag{7}$$

The real interest rate differential can then be written as:

$$\begin{aligned} r^*_{t,h} - r_{t,h} &= (i_{t,h} - \mathbb{E}_t(\pi_{t+h})) - (i^*_{t,h} - \mathbb{E}_t(\pi^*_{t+h})) \\ &= \mathbb{E}_t(xs_{t+h}) + \lambda_{t,h} - \mathbb{E}_t(\Delta q_{t+h}). \end{aligned} \tag{8}$$

Three factors influence the differential in real bond yields. First, the real yield differential is higher with a positive nominal expected excess return, or risk premium. Second, the Home real government bond yield is higher if it has a lower convenience yield.[19] Third, the differential is higher with a lower expected depreciation.

Table 4 shows the components of the decomposition in equation (8) over the two subperiods before and after 2010 for the euro-Swiss franc differentials.[20] The expected excess return and the expected real depreciation are computed by using survey expectations from Consensus Economics. Inflation expectations are computed in Section 2. In the last two lines of the table, we also show *ex post* excess return and real depreciation, using actual exchange rates and inflation rates.

Table 4: Decomposition of the real yield differential euro-Swiss franc with one-year horizon, in percent

Mean Variable	**1999Q1-2009Q4**	**2010Q1-2020Q4**	**Difference**
Real Differential: $r^* - r$	0.79	-1.08	-1.87
Expected excess return	1.34	2.49	1.15
Convenience Yield: λ	-0.21	-0.44	-0.23
-Expected real depreciation	-0.34	-3.09	-2.75
Ex post excess return	0.28	-2.06	-2.34
-Ex post real depreciation	0.38	0.83	0.45

Note: This decomposition is based on equation (8), according to which: real yield differential = expected excess return + convenience yield − expected real depreciation. The data comes from Datastream and Consensus Economics. All figures are expressed in percentage points.

Table 4 first shows that the real yield differential decreased by almost 2 percentage points over the two subperiods, which is substantial. This decrease can be explained by a more negative convenience yield and by an increase in expected real depreciation. In

[19] A recent literature points to the role of the convenience yields for government bonds in explaining the attractiveness of the US dollar (e.g., Jiang et al., 2018a; Engel and Wu, 2018; Valchev, 2020; Jiang et al., 2018b).

[20] For the whole period the real interest rate differential is about zero, so this decomposition is less interesting.

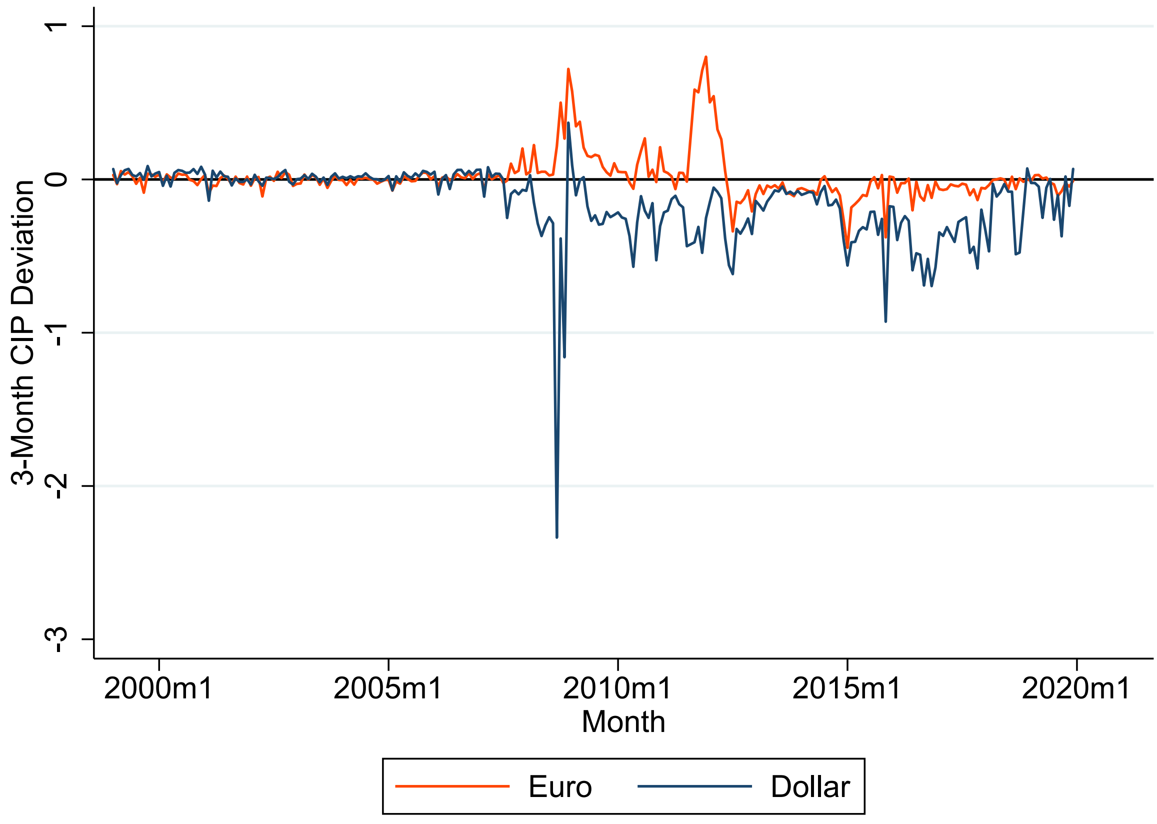
contrast, the increase in the expected excess return limits the decrease in the differential. We examine below these three elements. However, it is also useful to review the evidence on Covered Interest Parity (CIP). Indeed, deviations from CIP may affect expected excess returns. Moreover, risk-free yields are not always available at all maturities and researchers may use the forward discount instead to compute convenience yields. More precisely, define the forward discount $fd_{t,h} = f_{t,h} - s_t$, where $f_{t,h}$ is the log forward rate. Researchers sometimes assume CIP and replace $i^s_{t,h} - i^{s,*}_{t,h}$ by $fd_{t,h}$.

5.1 Deviations from Covered Interest Rate Parity

It is well known that there have been deviations from CIP since the Global Financial Crisis (GFC) (see Du et al., 2018). Figure 9 shows deviations from CIP for the Swiss franc with respect to the euro and the US dollar. More precisely the deviation, or cross-currency basis, is defined as:

$$\tau_{t,h} = i^{s,*}_{t,h} - i^s_{t,h} + fd_{t,h}. \tag{9}$$

Figure 9: Deviations from Covered Interest Rate Parity



This figure shows the cross-currency basis (in percentage points) between the Swiss franc and the euro and the US dollar, as defined in (9).

In Figure 9 we see that CIP deviations were negligible before 2007. There are large increases during the GFC and the Eurozone crisis with respect to the euro. However, the cross-currency basis has been negative in the last few years, especially with respect to the US dollar. This means that the US dollar interest rate is smaller than the interest of a synthetic dollar starting from the Swiss franc. This arbitrage opportunity, borrowing in dollars for a covered investment in Swiss francs, can be explained by the unwillingness or inability of financial intermediaries to take large foreign currency positions (e.g., see Borio et al., 2016; Cerutti et al., 2019). While there are short periods with large deviations from CIP, these deviations are small on average and can only play a marginal role in the analysis of real interest rate differentials.

5.2 Expected Excess Returns

The previous literature had shown that returns in Swiss francs were expected to be systematically lower than returns in foreign currency, especially the euro or previously the Deutsche mark. This implies that deviations from Uncovered Interest-rate Parity (UIP) are positive, i.e., that the expected appreciation of the Swiss franc was smaller than the interest rate differential. Kugler and Weder di Mauro (2005) conjectured that this evidence can be explained by a reverse peso problem for the Swiss franc, i.e., a small probability of a large appreciation. More generally, the Swiss franc is often seen as a safe haven currency (e.g., see Hoffmann and Suter, 2010; Ranaldo and Söderlind, 2010; Leutert, 2018).

However, returns in Swiss francs increased significantly after 2008 as the Swiss franc appreciated. This led, for example, Kugler and Weder di Mauro (2009) to wonder whether the expected return differential disappeared. If we look at *ex post* excess returns in Table 4, we see a significant decrease, implying a larger return in Swiss francs.[21] However, the evolution of *ex post* excess returns contrasts with the one of *expected* excess returns that increase. The difference comes from the fact that the Swiss franc appreciation in the last decade seems to have been unexpected. This is illustrated in Figure 10, which shows the evolution of the euro-Swiss franc exchange rate compared to 2-year forecasts (from Consensus Economics) shown at the end of each year. The Swiss franc has been expected to depreciate since 2010, while in most cases it appreciated.

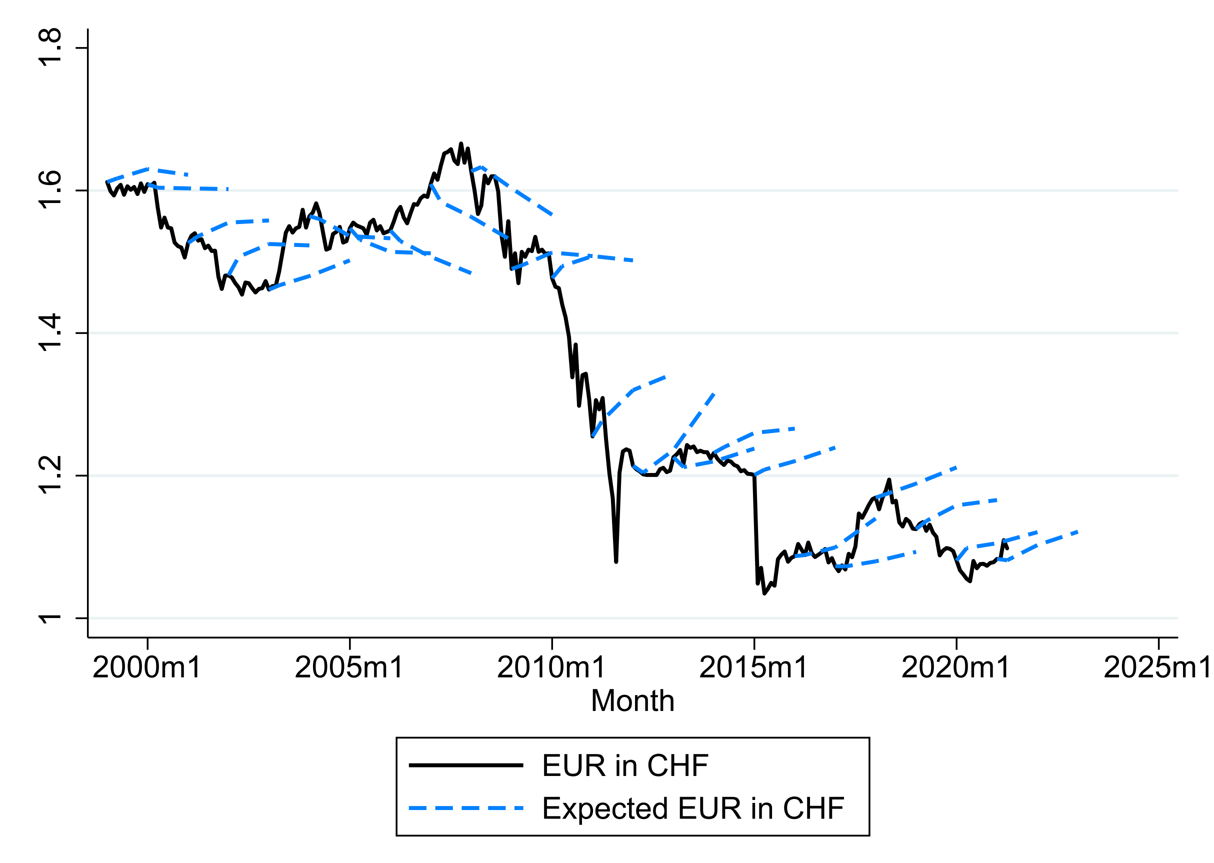
Therefore, the use of *ex post* data gives an incorrect picture of expected returns. Using exchange rate expectations instead of actual exchange rate changes, we see that expected excess returns have even increased, i.e., returns in Swiss francs are still expected to be lower. This would mean that, after a decade of turbulent times, the risk premium on the Swiss franc has increased. Moreover, the real appreciation of the Swiss franc is likely to reinforce this expected excess return as "overvalued" currencies are expected to depreciate. Consequently, expected excess returns or risk premia cannot explain the change in real interest rate differential.

5.3 Expected Real Depreciation

When UIP holds and abstracting from convenience yields (i.e., $\lambda_t = 0$ and $\mathbb{E}_t(xs_{t+h})$=0), the real interest rate parity is: $r_{t,h} = r^*_{t,h} + \mathbb{E}_t(\Delta q_{t+h})$. This means that if Home interest rates are higher, this is compensated by an expected depreciation. Table 4 shows a substantial increase in the expected real depreciation. This increase is even larger than the decrease in the real interest rate differential to compensate for the increase in expected excess returns. An expected real depreciation of 3.09 percent per year appears large, but the Swiss franc has appreciated sharply in the last decade. The empirical evidence shows that large real appreciations (or deviations from Purchasing Power Parity, PPP) are

[21] This decrease is even more significant if we split the sample in 2008.

Figure 10: Euro-Swiss franc: Exchange Rate and Expectations



This figure shows the euro-Swiss franc exchange rate, as well as 24-month expectations from Consensus Economics at the end of each year.

corrected over time. The expectations of nominal depreciation shown in Figure 10 are complemented by lower inflation expectations in Switzerland.

An interesting question is whether the Effective Lower Bound could partly explain the increase in expected real depreciation. In previous decades, the lower expected nominal return in Swiss francs was mainly captured by a lower nominal interest rate in Swiss francs (there was even an expected nominal *appreciation*). When the Swiss franc policy rate reached -0.75 percent in 2015, and the ECB lowered its policy rate, the nominal interest rate differential became very small. A positive expected nominal excess return must therefore be compensated by an expected nominal depreciation. If inflation rates are also close to zero, then we need a real depreciation.

6 Convenience Yields

In this section we focus on the convenience yield. It is of interest to analyze whether the recent analyses of convenient yields, applied to the US dollar, also apply to the Swiss franc (see Footnote 19). We start by showing the recent evolution of convenience yield for Switzerland. Then we revisit the literature on the link between the convenience yield and the exchange rate. Finally, we conduct an econometric study on the determinants of the convenience yield in Switzerland.

6.1 Evidence on Convenience Yields

As mentioned, in practice it is difficult to get data on risk-free yields for all maturities to compute $\lambda_{t,h}$. Therefore, researchers assume CIP and replace $i^s_{t,h} - i^{s,*}_{t,h}$ by $fd_{t,h}$. The alternative measure of the convenience yield is then:

$$\eta_{t,h} = i^*_{t,h} - i_{t,h} + fd_{t,h}. \tag{10}$$

Using the monthly data from Du et al. (2018), which is available from 1999 to 2019, Figure 11 shows the convenience yield $\eta_{t,h}$ at maturities of one, five, and ten years with respect to an average of ten countries.[22] We see that there is a clear decline in the convenience yield after 2009 at all maturities and that it stayed negative until recently.

This measure differs from $\lambda_{t,h}$ to the extent that there are deviations from CIP:[23]

$$\eta_{t,h} = \lambda_{t,h} + \tau_{t,h}. \tag{11}$$

Using one-year maturity, we can easily compute $\eta_{t,h}$, $\tau_{t,h}$ and $\lambda_{t,h}$, using Libor rates as risk-free rates. Figure 12 shows the evolution of $\eta_{t,h}$, $\tau_{t,h}$ and $\lambda_{t,h}$ for one-period bonds with respect to the US dollar and the euro. Except for a few periods, $\tau_{t,h}$ is small and fluctuations in $\eta_{t,h}$ and $\lambda_{t,h}$ are very similar.

The negative convenience yield for Swiss government bonds is surprising. For example, in our comparison with the euro, we consider German bonds. This means that, after hedging for exchange rate risk, the Swiss government bond yield has been higher than the German one in the last decade. Below we analyze the potential determinants of the convenience yield, in particular public debt and monetary policy. A declining convenience yield is surprising because the last decade coincides with a period of strong pressure on the Swiss franc. The analogy with the US dollar would tell us that an increase in the convenience yield should be associated with an appreciating currency, but this is not the case for the Swiss franc. However, it is interesting to examine the relationship between the convenience yield and the value of the Swiss franc, which we do in Subsection 6.2.

6.2 Convenience Yield and the Exchange Rate

Jiang et al. (2018a) and Engel and Wu (2018) relate the value of the convenience yield to the nominal exchange rate, focusing on one-year government yields. To analyze this relationship more precisely, Engel and Wu (2018) consider the following panel regression for the home country versus country j:

$$\Delta s_{j,t+h} = \alpha_j + \beta_1 q_{j,t-1} + \beta_2(\Delta\eta_{j,h,t}) + \beta_3(\Delta i^R_{j,h,t}) + \beta_4\eta_{j,h,t-1} + \beta_5 i^R_{j,h,t-1} + u_{j,h,t}, \tag{12}$$

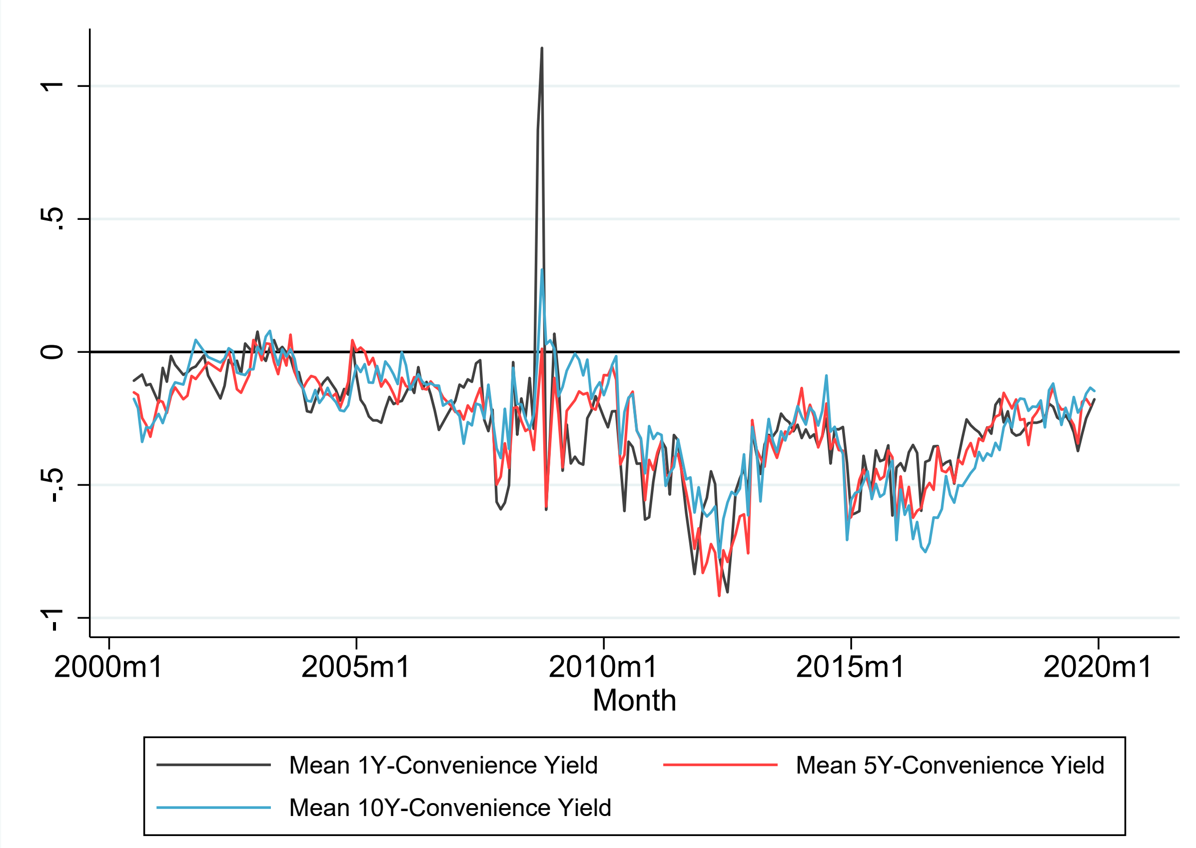
where $q_{j,t-1}$ is the log real bilateral exchange rate and $i^R_{j,h,t} = i_{t,h} - i_{j,h,t}$. They focus on one-year government yields and find that both the interest differential and the convenience yield are strongly significant. They also examine the differentiated impact of τ_t and λ_t (their Table 2A). Table 5 presents evidence on equation (12) for the Swiss franc, using the same methodology as in Engel and Wu (2018), for one-year yields and with monthly data.[24]

[22] The ten countries are Australia, Canada, Denmark, Germany, Japan, New Zealand, Norway, Sweden, UK and US. We will use the same set of ten countries throughout this section.

[23] There might also be a credit default component, but we focus on countries where this element has been negligible.

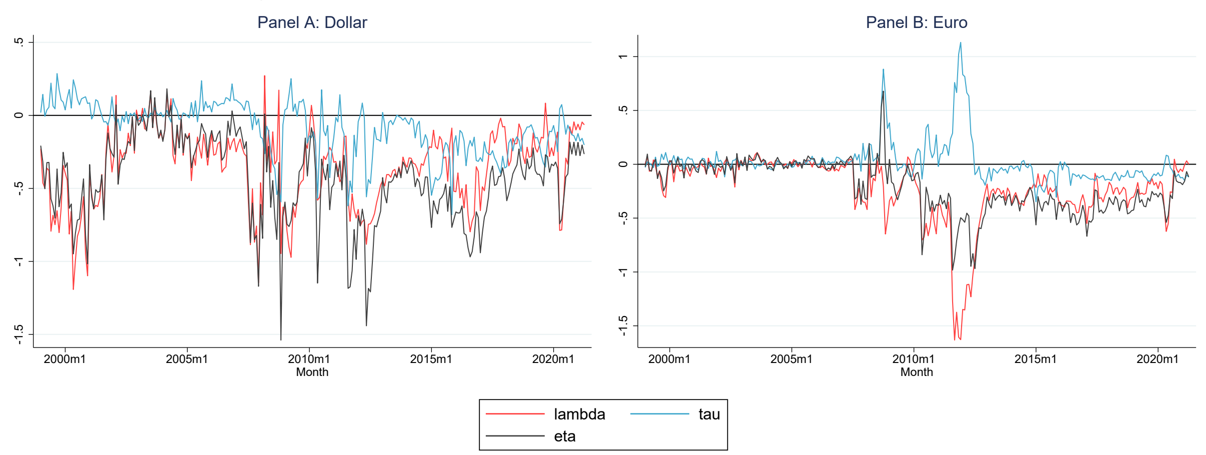
[24] We consider the Swiss franc with respect to 10 other currencies and use OLS with country dummies. The coefficients on lagged variables are included in the regression, but are not shown.

Figure 11: Convenience Yield - Swiss Franc



This figure shows the average convenience yields (expressed in percentage points), defined in (10), for Swiss franc government bonds at 1, 5, and 10 year maturities. Data source: Du et al. (2018).

Figure 12: Convenience Yield and Deviations from CIP



This figure shows the evolution of η (in black) and λ (in red), that are two measures of the convenience yields for the Swiss franc with respect to the euro and the US dollar at one-year maturity. η is based on equation (10); λ involves the forward discount; the difference between the two (τ, in blue) captures CIP deviations. Data source: Du et al. (2018) and Datastream. One unit corresponds to one percentage point.

Table 5: The Effect of Convenience Yields on Bilateral Exchange Rates

	(1)	(2)	(3)	(4)
$q_{j,t-1}$	-2.208***	-2.284***	-2.074***	-2.563***
	(0.340)	(0.369)	(0.323)	(0.400)
$\Delta\eta_{j,h,t}$	-1.289***	-0.395		
	(0.289)	(0.278)		
$\Delta i^R_{j,h,t}$	-1.485***		-1.023**	-1.282***
	(0.274)		(0.326)	(0.263)
$\Delta\lambda_{j,h,t}$				-0.987**
				(0.354)
$\Delta\tau_{j,h,t}$				-1.391***
				(0.322)
Observations	2666	2666	2666	2666
Within R-squared	0.0224	0.0119	0.0158	0.0348

The table reports the OLS estimates of equation (12) with country fixed effects. It uses the Swiss franc as the home currency and the other 10 currencies as foreign currency j. Standard errors clustered by country in parentheses. * $p < .1$, ** $p < .05$, *** $p < .01$.

Our results are quite similar to those of Engel and Wu (2018). Column (1) indicates strong significance for both the interest differential and the convenience yield (as in their Table 1A). Column (2) shows significance of the convenience yield without the interest differential, but with a lower R^2. Column (3) shows significance for the interest differential only. The last column shows that both τ_t and λ_t are significant. We see that the coefficient on λ is somewhat lower than the coefficient on η in column (1), which implies that deviations from CIP play a (small) role.

There are some econometric issues with regression (12), but we will not discuss them here. What we can conclude from Table 5 is that there is a significant negative relationship between the convenience yield and the nominal exchange rate. This means that an increase in the convenience yield is associated with an appreciation of the Swiss franc, which is what we would expect. However, this mechanism does account for a limited share of exchange rate fluctuations: with a decline in the convenience yield of about 0.5 percentage points (as seen in Figure 11) and a coefficient β_2 of about -1, the order of magnitude of the associated change in the exchange rate is of half a percentage point.

6.3 What Drives Convenience Yields?

In this section, we examine the role of potential drivers of the convenience yield. We perform a panel analysis of the Swiss bilateral convenience yield using quarterly data from January 2004 to March 2020 for the ten currencies listed in Section 6.1 (Footnote 22). One of the purposes of this section is to propose some explanations to the recent decline in the convenience yield. We show that both the purchase of government bonds by foreign central banks and the appreciation of the Swiss franc may have contributed to this decline.

In this empirical exercise, we examine the assumption that the convenience yield reflects the equilibrium price of Swiss government bonds, relative to foreign government bonds. A consequence of this assumption is that this relative price reflects the relative demand for Swiss government bonds, but also their relative supply. Namely, if some factors increase the demand for Swiss bonds relative to the demand for foreign bonds, then we expect the Swiss convenience yield to increase. Similarly, if some factors increase the supply of Swiss bonds relative to foreign bonds, we expect the Swiss convenience yield to decrease.

We use as demand drivers the VIX (CBOE Volatility Index), which is commonly used as a measure of global uncertainty. Under the assumption that Swiss government bonds are considered relatively safe, an increase in the VIX should lead to an increase in their demand and hence to an increase in the Swiss convenience yield. We also use the ratio of the Swiss real GDP to the foreign real GDP. Assuming that investors have a home bias in bond holding, we may expect that an increase in this ratio increases the Swiss convenience yield vis-à-vis the foreign country. Indeed, a higher GDP in Switzerland relative to the foreign country increases the relative demand for Swiss government bonds and must therefore increase the Swiss convenience yield. This variable may also capture capital flights from countries that go through a recession.

We also examine the role of the supply of public debt. Public debt has a potentially significant role for interest interest rates and especially the convenience yield (Rachel and Summers, 2019; Krishnamurthy and Vissing-Jorgensen, 2012; Du et al., 2018). One of the main purposes of this section is to estimate the elasticity of the government convenience yield to exogenous changes in the supply of government bonds. We expect this elasticity to be negative. Indeed, for the market to absorb an excess supply of public debt, the relative return on public debt must increase, which means that the convenience yield must decrease. Du et al. (2018) find that the US supply of bonds reduces the US convenience yield, while the foreign supply of bonds increases it. Our approach is very close to theirs, but we focus on Switzerland and deal with endogeneity issues. We also emphasize that a key element is not gross public debt *per se* but public debt *net* of central bank holdings, i.e. the amount of public debt that is available to the private sector. This implies that central bank purchases of government bonds matter as well. We will therefore also examine separately the role of these central bank purchases.

Finally, we will also examine the assumption that the exchange rate contributes to the convenience yield by affecting the supply of Swiss public bonds evaluated in foreign currency. If the exchange rate appreciates, then the supply of Swiss public bonds evaluated in foreign currency increases mechanically, which should depress its relative price. We thus expect an appreciation of the Swiss franc to decrease the Swiss convenience yield.

6.3.1 Panel data analysis

We estimate the effect of the supply of government bond debt on the convenience yield, measured by η, by estimating the following panel regression:

$$\begin{aligned}\eta_{t,h,j} = {} & \beta_1 \Delta \left(\tfrac{\text{Debt net of CB}}{GDP}\right)_{CH,t} + \beta_2 \Delta \left(\tfrac{\text{Debt net of CB}}{GDP}\right)_{j,t} + \beta_3 (i_{CH,t} - i_{j,t}) \\ & + \beta_4 \log(VIX_t) + \beta_6 \log\left(\tfrac{\text{Real GDP}_{CH,t}}{\text{Real GDP}_{j,t}}\right) + \beta_7 t + \beta_8 t^2 + \alpha_j + \epsilon_{it}\end{aligned} \tag{13}$$

where $\Delta(\text{Debt net of CB}/GDP)_{CH,t}$ is the change in the Swiss ratio of federal government debt (net of the Swiss National Bank holdings) to GDP in percentage points, $\Delta(\text{Debt net of CB}/GDP)_{j,t}$ is the change in country j's ratio of central government debt (net of country j's central bank holdings) to GDP in percentage points, $i_{CH,t} - i_{j,t}$ is the policy interest rate differential in basis points, Real $\text{GDP}_{CH,t}/\text{Real GDP}_{j,t}$ is the ratio of real GDPs, t and t^2 capture a quadratic trend and α_j are country fixed effects. The short-term interest differential is important because it is an element of the convenience yield measurement. While in theory the convenience yield is supposed to be independent from it, it could still be correlated with it if the government bond yield differential is sluggish. $\eta_{t,h,j}$ is the average convenience yield of Swiss government debt vis-à-vis country j's government debt at maturity h in quarter t, in basis points.[25] Our specification is close to Du et al. (2018), but we consider more controls than they do and regress the convenience yield in level on the change of government debt, instead of regressing it on the level of government debt as they do.[26]

Column (4) of Table 6 shows the results of our regression. Columns (1) and (2) do not include the country fixed effects in order to determine how far we can explain the convenience yield without them. In a similar spirit, column (1) shows the results without the quadratic trend. Relative GDP is included only after we have introduced fixed effects, because the unit is arbitrary (real GDPs are normalized to 100 in 2000). Note that it is important to include the quadratic trend, not only because it is significant and increases the fit of the regression from 30% to 43%, but also because it changes the magnitude of some coefficients (see columns (1) and (2)). When we include the country fixed effects, the fit increases as well, to reach 71% (see columns (2) and (3)). Finally, in column (4), we add relative GDP. The fit of column (4) is 75%, which is rather large.

Focusing on column (4), we see that the demand drivers have the expected signs. An increase in the VIX generates a statistically significant increase in the 10-year Swiss convenience yield. This positive coefficient may reflect the safe-haven nature of Swiss government debt. However, as we will see, this result is not very robust. The coefficient of the relative GDPs is also statistically significant, with a positive sign. This is consistent with home bias in asset holdings. An increase in domestic GDP increases the demand for home assets, which has a positive effect on the Swiss convenience yield. On the opposite, an increase in foreign GDP increases the demand for foreign assets, which has a negative effect on the Swiss convenience yield. The coefficient means that a 1% increase in relative GDP leads to an increase of the Swiss convenience yield by 3 basis points.

The coefficients of the supply of Swiss and foreign public debt are also significant and have the expected signs: An increase in Swiss government debt and a decline in the foreign government debt both decrease the Swiss convenience yield as they both make the Swiss debt relatively less scarce. Economically, the coefficients imply that an increase in the supply of Swiss government bonds equivalent to 1% of GDP decreases the Swiss convenience yield by 12 basis points. Similarly, an increase in the supply of government bonds in country j equivalent to 1% of its GDP increases the Swiss convenience yield vis-à-vis country j by 2 basis points. However, as we will discuss below, these coefficients are biased downwards. As we will show, correcting for that bias can substantially increase these coefficients.

[25] The countries in our panel are the same as in Table 5. We use quarterly government debt data from the IMF to measure the supply of government bonds, net of central bank holdings. Convenience yields come from Du et al. (2018). Swiss Treasury zero-coupon yields at maturities ranging from 1 to 10 years come from the Swiss National Bank. Monetary policy rates for the central banks of the countries in the panel come from Refinitiv Datastream, as well as the exchange rates of the Swiss Franc with respect to the other currencies. Data on the VIX comes from FRED. We use nominal GDP from the IMF to compute debt ratios and the real GDP from the OECD to compute the relative GDP. In our baseline regression, we focus on a maturity of 10 years.

[26] Table 16 (in Appendix F) provides the results using the level of debt.

Table 6: Drivers of the Convenience Yield

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) IV
Δ(Debt net of CB/GDP)$_{CH}$	-28***	-14***	-11***	-12***	-33***
	(3.1)	(2.8)	(2.6)	(2.2)	(7.3)
Δ(Debt net of CB/GDP)$_{j}$	2.1**	1.8*	1.9***	2.1***	2.2***
	(.94)	(.91)	(.63)	(.59)	(.6)
$i_{CH} - i_j$	.14***	.16***	.044***	.066***	.077***
	(.0098)	(.0082)	(.013)	(.012)	(.014)
$\log(VIX)$	.011	.12***	.14***	.094***	.083**
	(.041)	(.041)	(.034)	(.033)	(.035)
$\log\left(\frac{\text{Real GDP}_{CH}}{\text{Real GDP}_j}\right)$				2.9***	2.9***
				(.25)	(.28)
Observations	602	602	602	602	602
R-squared	0.30	0.43	0.71	0.75	0.72
Kleibergen-Paap F-stat					79.5
Hansen J-stat p-val					0.64
Quad. trend	No	Yes	Yes	Yes	Yes
Country FE	No	No	Yes	Yes	Yes

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Note: Quarterly data. The dependent variable is the convenience yield of Swiss government debt vis-à-vis country i's government debt in basis points, at a 10-year maturity, $\eta_{t,10year,j}$. Government debt is the change in the ratio of government debt net of central bank holdings to GDP, in percentage points. The log of relative GDP is multiplied by 100, so that the coefficients read as the effect of a 1 percent increase in relative GDP.

6.3.2 Instrumental variables

The coefficient of the change in Swiss public debt may not necessarily be interpreted as the causal effect of the supply of sovereign bonds on the convenience yield. That is, it may not necessarily reflect the actual supply-elasticity of the convenience yield. This coefficient merely reflects the correlation between the change in government debt and the convenience yield. This correlation is not driven only by "pure" supply shocks. It can also be driven by the strategic response of the Treasury to the change in the market price of public debt. For instance, if there is an increase in the demand for Swiss public bonds, then its price increases, which could incentivize the Treasury to issue bonds to take advantage of favorable market conditions. This price increase also means that the convenience yield increases, so this strategic behavior generates a positive correlation between government bond issuance and the convenience yield. This mechanism thus leads to a positive bias in β_1. This bias could attenuate β_1 or even turn it into a positive value. This is the first issue that we face in the identification of the supply-elasticity β_1.

The second issue is due to expectations. Market prices are forward-looking. This implies that increases in public debt that are anticipated by the market are already priced into the convenience yield. In the limit where the increase in public debt in a given quarter is fully anticipated, we should barely see any change in the convenience yield in that quarter. This mechanism also leads to an attenuation bias in β_1.

To deal with these two identification issues, we use instrumental-variable regressions. The instrumental-variable approach consists in building a measure of public debt using variables that we believe are strongly related to public debt issuance but are not affected by demand shocks and are unanticipated by markets. To build instrumental variables we use the so-called "high-frequency" (HF) method to identify surprises in the supply of government bonds, by exploiting real-time financial data around Swiss Treasury auctions. The HF approach consists in examining asset price movements in short time-windows around various macroeconomic news releases, the assumption being that of causality: Whatever occurs must be due to the news, since there is no reason to expect other systematic changes at such high frequencies. Here, the key assumption that we make is that during that day, the only news is about the supply of Swiss Treasury bonds.

We have obtained information about past auctions of long-term debt – with a maturity higher than 1 year – from the Federal Finance Administration, and especially the announcement and auction days. There are 10 to 12 auctions per year. Each auction starts with an official announcement by the Treasury (announcement days), specifying the maturity and coupon of the next auction. One or two days later, during which bidding occurs, the auction is settled and the price and quantities issued are published (auction days). We retrieved daily data on financial variables (secondary market price of Swiss Treasuries and Swiss Treasury futures) around auctions periods from the Refinitiv database. Matched with the former, the latter allowed us to examine Swiss government bond yields at different maturities shortly before and after Swiss Treasury auctions and auction announcements.[27]

In the Appendix, Figure 22 shows the distribution of the changes in the Swiss government bond yields at different maturities on "normal" days, on announcement days and on auction days. We can see that the changes on auction days are distributed around zero,

[27] It has been shown that Treasury auctions do generate market reactions in various countries. See, Fleming and Remolona (1999) and Smales (2020) for the response to U.S. Treasury auctions of bond and futures prices respectively. See Boffelli and Urga (2015) for the E.U., and Ahmad and Steeley (2008) for the U.K.

which we can interpret as markets being sometimes positively surprised by the amount issued, sometimes negatively. The distribution is flatter than in normal days, which suggests that these days are rich in information. Interestingly, we also see a similar pattern for announcement days. The auction calendar is known in advance and the Treasury does not communicate the targeted quantities on announcement days, so it might be surprising that markets seem to learn something on these days. However, note that the Treasury announces the maturity of the bonds that will be issued, so these surprises may reflect new information on this dimension, which is important to take into account. These yield changes, or "surprises", for different maturities, on announcement days or on auction days, are potential instruments.

We summarize these surprises using the principal component of surprises on announcement days and the principal component of surprises on auction days. Figure 23 shows these first principal components at daily frequencies. In order for these two variables to serve as instruments in the panel data analysis, we cumulate them over each quarter. Figure 24 shows the two resulting series. These are the two instruments that we use in the remaining analysis.

The results of the IV regression are shown in column (5) of Table 6. The coefficient of public debt becomes almost three times higher in absolute value. This suggests that our methodology does correct for the type of bias that we mentioned. The coefficient in column (5) means that the Swiss convenience yield would fall by 33 basis points if the Swiss public debt increased by the equivalent of 1% of GDP. In that case, increasing public debt by 1 billion CHF would lead the convenience yield to drop by 4.5 basis points. The coefficient is quite large, but this is not due to weak instruments, since the Kleibergen-Paap F-stat is very large. However, there is a lot of uncertainty on its actual level, given the large standard error (7). We perform robustness checks by looking at alternative sets of instruments (by adding the second principal components as instruments, by using directly the surprises for selected maturities, by computing surprises as the difference between the day before the announcement and after the auction), and we find coefficients between 29 and 32, with similar standard errors.[28]

Note that the coefficient of foreign debt is also affected by similar biases. We cannot correct for these biases in this report, but we may expect the estimated coefficient to similarly understate the effect of the supply of foreign public bonds.

In Appendix E, we examine the persistence of the effect of Swiss public debt issuance on convenience yields and its effect across different maturities. For all maturities (3 months to 10 years), the impact effect is very strong and of the same order of magnitude (-20 to -40 basis points for an increase of public debt equivalent to 1% GDP). The effect is very persistent for the maturities of 7 and 10 years. For maturities of 5, 3 and 1 years, the negative effect lasts for 2 to 3 quarters (beyond 3 quarters, the effect stays negative but becomes insignificant, with a few exceptions).[29]

Figure 13 illustrates how the relative supply of public debt could contribute to ex-

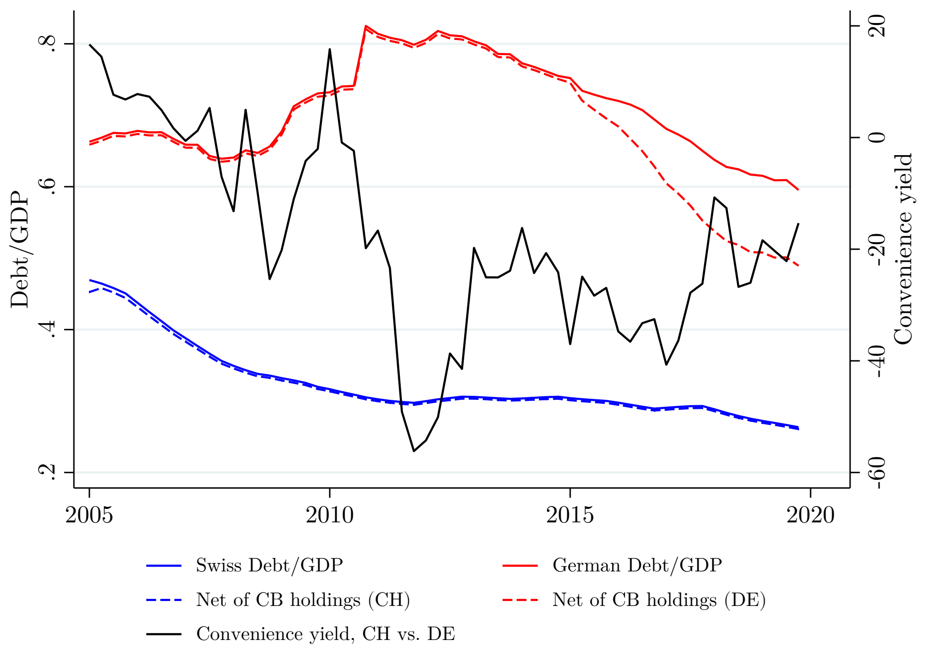
[28] Besides, in 16 in the Appendix, we show the results when using the debt to GDP ratio in level and not in difference. The coefficient is half as small, but still large (13 basis points).

[29] This vanishing effect of public debt could be explained by the crowding-in or crowding-out of safe assets that are close substitutes to public debt (Kacperczyk et al., 2021) for some maturities. Suppose that the government issues public debt, which, as we have shown, decreases the Swiss convenience yield. The relatively low price of Swiss safe assets becomes then a deterrent to the production of safe assets by the private sector. This mechanism contributes to re-inflating the price of safe assets in the medium run, which eventually increases the Swiss convenience yield, thus offsetting the initial effect. This offsetting effect takes 6 to 9 months to kick in.

plaining the evolution of convenience yields in recent years. It represents the convenience yield of the Swiss franc versus the euro, constructed with Swiss and German bond yields at five-year maturity, along with the Swiss and German public debts (as a percentage of GDP). We represent both the total debt and the total net of the domestic central bank's holdings. In 2010, the German debt stops increasing while the Swiss debt stops decreasing. This is the time where the Swiss franc-euro convenience yield turns persistently negative, which could result from a relative scarcity of German bonds. Later, in 2014, the convenience yield starts decreasing again. This coincides with an acceleration of the decline in the net supply of German bonds. Again, this potentially reflects the relative scarcity of German bonds. It appears from the figure that there is a role played by the supply of public debt, but also by central banks' interventions. We next examine more specifically the role of central bank interventions.

Note though that most of the drivers that we have identified so far contribute positively to the convenience yield after 2010, which seems to contradict the findings in Table 4. Looking at the Euro case documented in Figure 25, we see indeed that the Swiss real GDP has been increasing relative to the German GDP. We also see in Figure 13 that the Swiss government bonds have been declining as a share of GDP. However, in what follows, we identify other drivers that may have contributed negatively to the convenience yield after 2010.

Figure 13: The Supply of Government Bonds and the Convenience Yield



This figure represents the convenience yield of the Swiss franc versus the euro, constructed with Swiss and German bond yields at five-year maturity Du et al. (2018), along with the Swiss and German public debts (as a percentage of GDP), from the IFS (IMF). We represent both the total debt and the total net of the domestic central bank's holdings. The left scale corresponds to the public debt ratios while the right scale corresponds to the convenience yield.

6.3.3 The role of central banks' sovereign debt purchases

In this section, we examine the role of central banks' purchases of public bonds. As illustrated in Figure 13, these purchases have been important in driving the convenience yield. To test this assumption, we estimate an equation similar to equation (13), where we add $\Delta \log(CB/GDP)_j$, which is the growth rate of the central banks holdings of domestic government debt to GDP ratio in country j, using IMF data.[30] We expect the effect of this variable on the Swiss convenience yield to be negative, as central bank purchases of foreign public bonds make foreign bonds relatively scarcer as compared to Swiss government debt. In order to isolate the effect of the central bank purchases of domestic public bonds from the effect of public bonds, we replace government bonds net of central bank purchases by gross domestic debt in the regressions. Therefore, $\Delta(\text{Debt net of CB/GDP})_{CH}$ and $\Delta(\text{Debt net of CB/GDP})_j$ are replaced respectively by $\Delta(\text{Debt/GDP})_{CH}$ and $\Delta(\text{Debt/GDP})_j$.

We would also like to examine the more specific role of the ECB's quantitative easing (QE) policy. The ECB's QE consisted in buying government bonds but also in supporting the private sector through the Long-Term Refinancing Operations for instance , which benefited commercial banks, the Asset-backed Securities Purchasing Program or the Corporate Sector Purchase Program. Through QE the ECB could potentially reduce the perceived riskiness of the Euro area and make European government bonds more attractive. We expect this policy to have an effect on the convenience yield beyond the mere ECB's government purchases. We thus also add $\Delta \log\left(\text{ECB assets}/GDP_{EA12}\right) \#(j = EURO)$, which is the growth rate of the ECB's assets to Euro-12 GDP ratio, multiplied by a dummy equal to one when $j = EURO$, and zero otherwise. The data comes from the ECB. We expect the effect of this variable on the Swiss convenience yield to be negative, because it makes European bonds relatively more attractive by reducing the risk associated to the Euro area. Later, when we consider the role of the exchange rate, we will examine the policy of the SNB as well.

The results are shown in columns (1) and (2) of Table 7. The coefficients have the expected signs and are significant. Consider first central bank holdings. If the ratio of central bank holdings of public debt to GDP increases by 1% in country j, then the Swiss convenience yield vis-à-vis country j decreases by 0.07 basis points. This might seem small but the standard deviation of this variable is equal to 23 in our sample. This corresponds to close to 1.5 basis points. In the case of the euro and Germany, this ratio has been multiplied by 10 between 2015 and 2020, as shown in Figure 25 in the Appendix. Alone, these purchases would have contributed to a decline in the convenience yield of 70 basis points. So, quantitatively, these purchases can have a potentially large effect. However, since they are correlated with other factors, we must consider these numbers with great caution.

Consider now the role of ECB's asset purchases. If the ECB's assets to GDP ratio increases by 1%, then the Swiss convenience yield vis-à-vis the Euro decreases by 0.58 basis points. The standard deviation of this variable is equal to 7 in our sample. This corresponds to about 4 basis points. The assets of the ECB have tripled between 2009 and 2019, as shown in Figure 25, which amounts to more than a 100 basis points decline in the Swiss convenience yield vis-à-vis the Euro. Again, we can, with caution, assume that they played a significant role.

In Table 18 of the Appendix we show the results for other maturities. Central banks'

[30] In order to deal with zero values, we compute the log as $\log(CB/GDP + 0.01)$.

Table 7: The Role of Central Banks' Sovereign Debt Purchases and the Exchange Rate

	(1) OLS	(2) OLS	(3) OLS	(4) OLS
$\Delta(\text{Debt/GDP})_{CH}$	-16***	-16***	-16***	-12***
	(2.5)	(2.4)	(2.6)	(2.7)
$\Delta(\text{Debt/GDP})_j$	2.6***	2.8***	2.7***	2.3***
	(.6)	(.62)	(.75)	(.72)
$i_{CH} - i_j$	.069***	.066***	.092***	.11***
	(.012)	(.012)	(.013)	(.014)
$\log(VIX)$	.092***	.095***	.035	.055
	(.033)	(.033)	(.037)	(.039)
$\log\left(\frac{\text{Real GDP}_{CH}}{\text{Real GDP}_j}\right)$	2.8***	2.7***	3.7***	4.1***
	(.24)	(.25)	(.28)	(.31)
$\Delta\log(CB/GDP)_j$		-.07***	-.07***	-.059***
		(.016)	(.017)	(.019)
$\Delta\log\left(\frac{\text{ECB assets}}{GDP_{EA12}}\right)\#(j = EURO)$		-.58**	-.67**	-.51**
		(.25)	(.26)	(.25)
τ_t			.12*	.089
			(.061)	(.062)
$s_{t-1,j}$				.44***
				(.14)
$\Delta(FX/GDP)_{CH}$				-.55*
				(.32)
Observations	602	602	507	507
R-squared	0.76	0.76	0.78	0.79
Quad. trend	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Note: See the note of Table 6. The logs of the ratio of CB holdings to GDP and of the ratio of ECB assets to GDP are multiplied by 100, so that the coefficients read as the effect of a 1 percent increase in these ratios. τ is the deviation from CIP defined in equation (9). An increase in the log exchange rate $s_{t-1,j}$ means that the Swiss franc depreciates vis-à-vis the other currency. The log exchange rate is multiplied by 100, so that the coefficient reads as the effect of a 1 percent depreciation in the Swiss franc. The ratio of FX reserves to GDP is also multiplied by 100, so that the coefficient reads as the effect of an increase in FX reserves equivalent to 1% of GDP.

sovereign debt purchases and ECB's QE policy have larger and more significant effects for longer maturities. Indeed, these policies usually target the yield curve and a reduction in the maturity premium.

6.3.4 The role of the exchange rate

We next examine the role of the exchange rate. As explained earlier, we conjecture that the exchange rate affects the convenience yield through a valuation effect: An appreciation of the Swiss franc inflates the foreign-currency value of Swiss government bonds, which may have a negative effect on the convenience yield. To test these valuation effects, we introduce the log of the bilateral exchange rate $s_{t,j}$, which is the price in CHF of currency j. We use the first lag in order to limit endogeneity issues. We expect the coefficient of the exchange rate to have a positive sign (an appreciation of the Swiss franc generates a decrease in the exchange rate).

The exchange rate may have a second role, but this time due to measurement. Indeed, we measure the convenience yield by η, using the data of Du et al. (2018), which is constructed under the assumption that the covered interest parity holds. However, as documented by Du et al. (2018), and as illustrated in Figure 9, there are deviations from CIP. Neglecting these deviations may bias our results. We therefore take this into account by introducing τ, the deviation from CIP defined in 9, in the regression. Unfortunately, only the CIP deviation at the one-year maturity $\tau_{t,1year,j}$ is available.

Finally, note that the periods of strong exchange rate appreciation (2009-2011, 2015) correspond to periods where monetary policy became constrained by the Zero or Effective Lower Bounds on the interest rate. Indeed, in 2009, the policy rate dropped below 50 basis points (but remained positive). In 2015, it dropped below zero as the SNB abandoned the floor on the Euro-Swiss franc exchange rate. These periods were characterized not only by a limited ability of the SNB to fight the appreciation of the exchange rate through the policy rate, but also through massive foreign exchange interventions. The interventions may have also contributed to lower the convenience yield, as the demand for foreign bonds by the SNB increases. We therefore introduce changes in the ratio of the SNB official reserve assets and other foreign currency assets to GDP, $\Delta(FX/GDP)_{t,CH}$, for their own sake, but also to check the robustness of our results.

The results are shown in columns (3) and (4) of Table 7. As shown in column (3), the CIP deviation's coefficient is positive and significant. One basis point increase in the CIP deviation increases the convenience yield by 0.12 basis point. This positive coefficient is reflecting the fact that τ introduces a wedge between η and λ. The coefficient is not 1 as in equation (11), because τ is correlated to the other regressors, and because of the maturity mismatch between $\eta_{t,10year,j}$ and $\tau_{t,1year,j}$.[31] Importantly, when the CIP deviations are introduced, the coefficients change a little but the results remain robust. Only the VIX coefficient becomes insignificant. Cerutti et al. (2019) find indeed that the VIX is an important determinant of CIP deviations. These results thus suggest that the VIX may be affecting the convenience yield only through the measurement error. We conclude that the effect of the VIX is not robust.

Column (4) shows the results when we introduce the lagged exchange rate and changes in the SNB's foreign reserves. The coefficient of the exchange rate is significantly positive and economically large. As shown in Figure 25, the Swiss franc appreciated by 25% in 2009-2011, which per se would have generated a decline in the convenience yield by 11

[31] In the regression of $\eta_{t,1year,j}$, the coefficient of $\tau_{t,1year,j}$ jumps to 0.36.

basis points. In 2015, it appreciated by 15%, which could have accounted for a 7 basis point decline. Up to 16 basis points out of the 23 basis point decline documented in Table 4 could be explained by the exchange rate.

The coefficient of foreign exchange interventions is negative and significant, as expected, and the coefficient of the exchange rate remains unchanged. In quantitative terms, this coefficient means that an increase in foreign reserves equivalent to 1% of GDP decreases the convenience yield by 0.55 basis points. This is extremely high. Between 2009 and 2020, the SNB bought the equivalent of the entire Swiss GDP in foreign reserves, as Figure 25 shows. This, taken independently from the other explanatory variables, generates a 55 basis point decrease in the convenience yield. Again, these numbers should be considered cautiously. Indeed, the estimated coefficient must be interpreted as the effect of the exogenous foreign exchange interventions, that is, the part that is unrelated to the other explanatory variables in the regression. Since changes in foreign exchange reserves are highly correlated with the exchange rate, the nominal interest rate differential, the ECB interventions and real GDP (and probably also all the other variables), and are thus not exogenous, we must not expect that the totality of the change in foreign reserves observed during the period have affected the convenience yield with that magnitude. The same argument holds for the other coefficients.[32]

All in all, we find evidence that foreign central bank policies, foreign exchange interventions by the SNB and the exchange rate may have contributed to the fall in the Swiss convenience yield since 2010. Our methodology does not allow us to quantitatively decompose the fall in the convenience yield into the contribution of these different drivers nor to estimate their joint total effect, but our results suggest that their potential contribution may have an order of magnitude similar to the observed evolution of the convenience yield.

7 Conclusion

The decline in real interest rates in recent decades is a global phenomenon and is not specific to Switzerland. One of the initial objectives of our study was to identify econometrically the determinants of Swiss real interest rates. However, we have found that Swiss real yields have followed closely global yields in recent decades. This means that Swiss real rates are determined mainly by global, rather than domestic, factors. This is true both for our measures of ex-ante real rates and for our estimates of equilibrium or trends in real rates. The remaining cross-country differences cannot be explained by standard real rates determinants. This also means that we no longer have a "Swiss Interest Rate Island" (Baltensperger and Kugler, 2017).

Critics sometimes point to the policy of the Swiss National Bank as responsible for low interest rates. Our analysis illustrates why it is not the case. The decline in real interest rates is not only a global phenomenon but has been somewhat smaller in Switzerland than in some other countries, in particular Germany. If anything, Swiss monetary policy has limited the decline in Swiss real rates compared to Germany. Foreign exchange interventions, which have increased by the same magnitude as the Swiss GDP, have contributed to the decline in the Swiss convenience yield and have therefore put upward pressure

[32]Going further would require identifying all the independent shocks that affect the previous set of variables. This task, that would require various additional (and debatable) assumptions, is outside the scope of this study.

on the Swiss real rate. Moreover, it is the inability to decrease short-term interest rate that can explain the recent evolution. Since Swiss franc interest rates have traditionally been lower, nominal interest rates in other countries have had more space to decline. At the same time, inflation expectations remained lower in Switzerland, which explains the smaller decline in real rates.

The COVID-19 crisis is also impacting real interest rates, although our empirical analysis could not really analyze the recent months due to missing data. The economic crisis in 2020-2021 has a depressing impact on interest rates. Moreover, the existing evidence shows that the pandemic has exacerbated the fundamental factors that are pushing towards lower real rates. On the one hand, private saving has significantly increased, both because of precautionary saving and the inability to consume some goods and services. On the other hand, investment demand has declined, both because of an increase in uncertainty and various constraints associated with the pandemic.

But the important question is how real interest rates will evolve in future years. Our estimates of long-term trends point to persistent low rates and the current crisis is likely to postpone future increases in real interest rates. Evidence on previous pandemics show that real interest rates remain low for decades (see Jordà et al., 2020). The open question is whether this effect will be as long lasting for the current pandemic. The recoveries in late 2021 and 2022, associated with an ambitious fiscal program in the US and the soaring public debt in most countries will put an upward pressure on real interest rates. On the other hand, the COVID-19 crisis may have a scarring impact, as discussed in the recent literature. The increase in inequalities in the wake of the current crisis puts a downward pressure on interest rates. Moreover, there may be long-lasting changes that might weaken investment or foster saving. These changes include, e.g., a loss in human capital due to the disruption of the pandemic, firm restructuring in various sectors, or a shift towards technological/services sector. Moreover, the dramatic situation during the COVID crisis may affect risk aversion or the perception of future extreme negative shocks (see Kozlowski et al., 2020). All these factors would imply a sustained period of very low real interest rates, in Switzerland and most other countries. Future research will determine how large and persistent these effects are. But here again we are dealing with a global phenomenon that affects global interest rates.

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— APPENDIX —

A Interpolating Nominal Yields

A.1 Overall approach

We assume that, for each country j, each date t and each maturity τ, the nominal yield-to-maturity on a government bond is given by the Nelson-Siegel-Svensson parametric function, that is:[33]

$$\begin{aligned} i_{j,t}(\tau) &= \beta_{j,0,t} + \left(\frac{1-e^{-\tau/\lambda_1}}{\tau/\lambda_1}\right)\beta_{j,1,t} + \left(\left(\frac{1-e^{-\tau/\lambda_1}}{\tau/\lambda_1}\right) - e^{-\tau/\lambda_1}\right)\beta_{j,2,t} + \\ & \left(\left(\frac{1-e^{-\tau/\lambda_2}}{\tau/\lambda_2}\right) - e^{-\tau/\lambda_2}\right)\beta_{j,3,t}. \end{aligned} \tag{14}$$

Therefore, once the (static) parameters λ_1 and λ_2 and the (dynamic) factors $\beta_{j,0,t}$, $\beta_{j,1,t}$, $\beta_{j,2,t}$, $\beta_{j,3,t}$ are known, then one can compute the whole term structure of nominal yields for country j and date t. We further posit that the $\beta_{j,k,t}$'s follow auto-regressive processes (15) and allow for measurement errors between the smoothed yields predicted by (14) and the observed ones. The Kalman filter is then used to estimate the static parameters (by maximum-likelihood) and the dynamic latent factors (the $\beta_{j,k,t}$'s). Kalman-filter techniques are particularly relevant in the present context, where the number of observations per date is time-dependent (with few observations at the beginning of the sample). These techniques are indeed easily adjusted to account for missing data (see e.g. Harvey and Pierse, 1984; Harvey, 1989); we exploit this property in the early part of our sample, for which yield data are missing for some countries, or not available at the quarterly frequency.

A.2 State-space model

We assume that the "β" factors follow auto-regressive processes of order one. Specifically:

$$\boldsymbol{\beta}_{j,t} = \begin{bmatrix} \beta_{j,0,t} \\ \beta_{j,1,t} \\ \beta_{j,2,t} \\ \beta_{j,3,t} \end{bmatrix} = \underbrace{\begin{bmatrix} \mu_{\beta,0} \\ \mu_{\beta,1} \\ \mu_{\beta,2} \\ \mu_{\beta,3} \end{bmatrix}}_{=\mu_\beta} + \underbrace{\begin{bmatrix} \phi_{\beta,0} & 0 & 0 & 0 \\ 0 & \phi_{\beta,1} & 0 & 0 \\ 0 & 0 & \phi_{\beta,2} & 0 \\ 0 & 0 & 0 & \phi_{\beta,3} \end{bmatrix}}_{=\Phi_\beta} \boldsymbol{\beta}_{j,t-1} + \boldsymbol{\varepsilon}_{\beta,i,t}, \tag{15}$$

with $\varepsilon_{\beta,t} \sim \mathcal{N}(0, \Sigma_\beta)$.

[33] See Nelson and Siegel (1987) and Svensson (1994).

We consider a set of m maturities: $\{\tau_1, \dots, \tau_m\}$ and we denote by $\mathbf{y}_{j,t}$ the m-dimensional vector gathering country-i yields associated with these maturities. We have:

$$\mathbf{y}_{j,t} = \underbrace{\left[\begin{array}{cccc} 1 & \left(\frac{1-e^{-\tau_1/\lambda_1}}{\tau_1/\lambda_1}\right) & \left(\left(\frac{1-e^{-\tau_1/\lambda_1}}{\tau_1/\lambda_1}\right) - e^{-\tau_1/\lambda_1}\right) & \left(\left(\frac{1-e^{-\tau_1/\lambda_2}}{\tau_1/\lambda_2}\right) - e^{-\tau_1/\lambda_2}\right) \\ \vdots & \vdots & \vdots & \\ 1 & \left(\frac{1-e^{-\tau_m/\lambda_1}}{\tau_m/\lambda_1}\right) & \left(\left(\frac{1-e^{-\tau_m/\lambda_1}}{\tau_m/\lambda_1}\right) - e^{-\tau_m/\lambda_1}\right) & \left(\left(\frac{1-e^{-\tau_m/\lambda_2}}{\tau_m/\lambda_2}\right) - e^{-\tau_m/\lambda_2}\right) \end{array}\right]}_{=\Gamma(\lambda)} \boldsymbol{\beta}_{j,t}.$$

Stacking all country-specific factors $\boldsymbol{\beta}_{j,t}$ in a $4N$-dimensional vector $\boldsymbol{\beta}_t$, we get:

$$\mathbf{y}_t = \underbrace{(\mathbf{Id}_{N\times N} \otimes \Gamma(\lambda))}_{=\Phi_\beta} \cdot \boldsymbol{\beta}_t.$$

Let us denote by $\mathbf{y}_t^o$ the vector of observed yields (with N countries, this vector is of dimension $8N$ since eight maturities are considered: 3 months, 1, 2, 3, 5, 7 and 10 years). Assuming the existence of i.i.d. normal measurement errors (ν_t, say), we get:

$$\mathbf{y}_t^o = \Phi_\beta \cdot \boldsymbol{\beta}_t + \boldsymbol{\nu}_t, \tag{16}$$

where the components of $\boldsymbol{\nu}_t$ are *i.i.d.* $\mathcal{N}(0, \sigma_\nu^2)$.

The previous equation constitutes the measurement equation of the state-space model. The transition equations read:

$$\boldsymbol{\beta}_t = (\mathbf{1}_{N\times 1} \otimes \mu_\beta) + (\mathbf{Id}_{N\times N} \otimes \Phi_\beta)\boldsymbol{\beta}_{t-1} + \boldsymbol{\varepsilon}_{\beta,t}. \tag{17}$$

A.3 Estimation of the model parameterization

The Kalman filter can be used to compute the log-likelihood associated with this state-space model. Accordingly, one can estimate model parameters by maximum likelihood. Note that this can done in spite of the fact that, for some dates, countries and maturities, some yields are unobserved (see Table 13); the Kalman can indeed handle missing data (Harvey and Pierse, 1984; Harvey, 1989). Table 8 shows estimated parameters.

For simplicity, the maximisation of the log-likelihood function is based on a diagonal matrix Σ_β (otherwise the number of parameters to estimate would be numerically highly demanding). Once the estimation is done, we use the Kalman smoother to get estimates of the β factors and deduce estimates of their innovations ($\boldsymbol{\varepsilon}_{\beta,i,t}$ in (15)). We further compute the sample correlation matrix of these estimates, considering only the period 1980-2020, where most of the yields are observed. We then adjust Σ_β for it to be consistent with this sample correlation structure. We check that this effectively increase the log-likelihood.

B Modelling Inflation Expectations

B.1 Processes followed by the inflation components

As explained in Subsection 2.2.3, we assume that, on date t, the inflation rate of country j can be split into three components:

$$\pi_{j,t} = \overline{\pi}_{j,t} + \tilde{\pi}_{j,t} + \xi_{j,t}, \tag{18}$$

Table 8: Parameterization of dynamic Nelson-Siegel-Svensson model

Param.	Value	Param.	Value	Param.	Value
$\mu_{\beta,0}$	0.007	$\Phi_{\beta,0}$	0.998	$\sigma_{\beta,0}$	0.302
$\mu_{\beta,1}$	-0.094	$\Phi_{\beta,1}$	0.947	$\sigma_{\beta,1}$	0.681
$\mu_{\beta,2}$	-0.033	$\Phi_{\beta,2}$	0.949	$\sigma_{\beta,2}$	1.459
$\mu_{\beta,3}$	-0.028	$\Phi_{\beta,3}$	0.989	$\sigma_{\beta,3}$	1.045
λ_1	1.350	λ_2	3.504	σ_ν	0.264

Note: $\sigma_{\beta,0}$, $\sigma_{\beta,1}$, $\sigma_{\beta,2}$ and $\sigma_{\beta,3}$ are the standard deviations of the $\varepsilon_{\beta,i,t}$'s (equation 15), i.e. the square roots of the diagonal entries of Σ_β; σ_ν is the standard deviation of the measurement errors (see equation 16).

where $\xi_{j,t}$ is a Gaussian zero-mean shock, where $\overline{\pi}_{j,t}$ is a trend component and $\tilde{\pi}_{j,t}$ is a stationary process. Specifically:

$$\overline{\pi}_{j,t} = \overline{\pi}_{j,t-1} + \varepsilon_{j,t}, \tag{19}$$

$$\tilde{\pi}_{j,t} = \phi\tilde{\pi}_{j,t-1} + \eta_{j,t}. \tag{20}$$

Moreover, we posit:

$$\varepsilon_t = [\varepsilon_{1,t}, \dots, \varepsilon_{N,t}]' \sim \mathcal{N}(0, \Sigma_\varepsilon) \quad \text{and} \quad \eta_t = [\eta_{1,t}, \dots, \eta_{N,t}]' \sim \mathcal{N}(0, \Sigma_\eta),$$

and we assume that the $\xi_{j,t}$'s are independent and distributed as $\mathcal{N}(0, \sigma^2_{\xi,t})$. Hence, the variance of the $\xi_{j,t}$, that is $\sigma^2_{\xi,t}$, can be time-dependent, thereby allowing for inflation heteroskedasticity in the model. Specifically, we assume that $\sigma_{\xi,t}$ is given by:

$$\sigma_{\xi,t} = \sigma_\xi \frac{1}{1 + \exp(\theta_0 + \theta_1 t)},$$

which is valued in $[0, \sigma_\xi]$. We impose $\theta_1 > 0$, implying that $\sigma_{\xi,t}$ is decreasing through time, capturing the secular decrease in the inflation volatility.

B.2 State-space model without survey-based inflation forecasts

If the three components appearing in (18) were observed on each date t, then inflation expectations would be easy to compute, as we have:

$$\mathbb{E}_t(\pi_{j,t+h}) = \bar{\pi}_{j,t} + \phi^h \tilde{\pi}_{j,t}, \tag{21}$$

where ϕ is the autoregressive parameter of process $\tilde{\pi}_{j,t}$ (see eq. 20). But the decomposition (18) is not observed. As a result, to get estimates of $\mathbb{E}_t(\pi_{j,t+h})$, one has to infer values of $\bar{\pi}_{j,t}$ and $\tilde{\pi}_{j,t}$ (as well as of the parameter ϕ). We employ the Kalman filter to do so.

When the state-space model is not augmented with survey-based forecasts, equations (18) constitute the only measurement equations, and equations (19) and (20) are the transition equations. In matrix form, the state-space model is given by:

$$\pi_t = \underbrace{([1 \quad 1] \otimes \mathbf{Id}_N)}_{=:A} \cdot \begin{bmatrix} \overline{\pi}_t \\ \tilde{\pi}_t \end{bmatrix} + \xi_t \tag{22}$$

$$\begin{bmatrix} \overline{\pi}_t \\ \tilde{\pi}_t \end{bmatrix} = \underbrace{\left(\begin{bmatrix} 1 & 0 \\ 0 & \phi \end{bmatrix} \otimes \mathbf{Id}_N \right)}_{=:\Phi} \cdot \begin{bmatrix} \overline{\pi}_{t-1} \\ \tilde{\pi}_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_t \\ \eta_t \end{bmatrix}. \tag{23}$$

B.3 State-space model with survey-based inflation forecasts

The state-space model features additional measurement equations when survey-based forecasts are introduced in the estimation approach (as in Grishchenko et al., 2019; Aruoba, 2020). Specifically, these additional measurement equations are of the form:

$$\begin{aligned} SPF_{j,t,\tau} &= \mathbb{E}_t(\pi_{j,t+\tau}) + \nu_{j,t,\tau} \\ &= \bar{\pi}_{j,t} + \phi^{\tau}\tilde{\pi}_{j,t} + \nu_{j,t,\tau}, \end{aligned} \tag{24}$$

where $SPF_{j,t,h}$ denotes a survey-based inflation forecasts, for country j and horizon τ, that is released (or observed) on date t. The measurement error $\nu_{j,t,h}$ allows for discrepancies between the observed survey-based forecasts ($SPF_{j,t,\tau}$) and the model-implied forecasts ($\bar{\pi}_{j,t} + \phi^{\tau}\tilde{\pi}_{j,t}$). As reported in Table 2, we do not observe SPFs for all countries, horizon and dates; but the information conveyed by a few observed SPF is however extremely valuable to recover inflation expectations at all horizons. To clarify this point, consider the extreme case where $\nu_{j,t,\tau} = \xi_{j,t} = 0$. In this case, equations (22) and (24) form a system with two equations and two unknowns; so $\bar{\pi}_{j,t}$ and $\tilde{\pi}_{j,t}$ are easily deduced; (21) can further be applied to recover date-t inflation expectations at any horizon. Moreover, because we allow for correlations between the inflation components of the different countries, the information conveyed by the survey-based forecast of some countries is exploited for all countries.

In this case, (22) is replaced by:

$$\begin{bmatrix} \pi_t \\ SPF_t \end{bmatrix} = \begin{bmatrix} A \\ B \end{bmatrix} \cdot \begin{bmatrix} \bar{\pi}_t \\ \tilde{\pi}_t \end{bmatrix} + \begin{bmatrix} \xi_t \\ \nu_t \end{bmatrix} \tag{25}$$

where the coefficients of B stem from the definition of the considered surveys, as well as the countries and horizons targeted by the the survey. Regarding the definition of the survey, note for instance that the 5-year forecast of the SPF of the Federal Reserve of Philadelphia (see Table 2) corresponds to the annualized growth rate of the price index between t and $t + 5\,\text{yrs}$. By contrast, the 5-year forecast of the ECB SPF is the increase in price between $t + 4\,\text{yrs}$ and $t + 5\,\text{yrs}$.

This implies that we have:

$$US.SPF_{t,5yrs} = \tilde{\pi}_{US,t} + \frac{1}{5}\Big(\phi^4 + (\phi^4)^2 + (\phi^4)^3 + (\phi^4)^4 + (\phi^4)^5\Big)\tilde{\pi}_{US} + \nu_{US,t},$$

and

$$ECB.SPF_{t,5yrs} = \tilde{\pi}_{EZ,t} + (\phi^4)^5\tilde{\pi}_{EZ} + \nu_{EZ,t}.$$

Regarding the latter equation, concerning the eurozone (EZ), note that the euro area is not included as such in our set of 17 geographical entities. However, our dataset comprises 8 large countries of the euro area, namely Belgium, Finland, France, Germany, Italy, the Netherlands, Portugal and Spain. Also, we approximate for the eurozone inflation rate $\pi_{EZ,t}$ with a weighted combination of the inflation rates of the 8 above-mentioned countries, using 2019 GDP-based weights.

B.4 Estimation

Some of the model parameters are estimated by maximum-likelihood, the likelihood function behind obtained from the Kalman filter. Before running the estimation, we remove observed year-on-year inflation rates below -10% and above $+20\%$. Table 9 presents the resulting model parameterization. The superscript (a) indicates those parameters that are estimated by maximum likelihood. The other parameters are set for the different components to be consistent with their intended interpretation. Typically, σ_ε (the standard deviation of the innovations to the long-run component, see equation 19) is set to a relatively low value, so as to avoid having too large changes in this low-frequency components between two consecutive periods.

As in A.3, after the maximum-likelihood estimation, we compute the sample correlation matrix of the estimated $[\varepsilon_t, \eta_t]$ (see equation 23) and modify the covariance matrix of these innovations to be consistent with this correlation structure. We check that the log-likelihood is increased by this procedure. Doing so allows to account for the correlation across international inflation components; it notably implies that the final estimates of inflation expectations for all countries benefit from the information embedded in observed data in other countries (including survey-based forecasts).

Table 9: Parameterization of the inflation state-space model

Param.	**Value**	**Param.**	**Value**
σ_ε	0.20	σ_ξ	3.00
ϕ	$0.80^{(a)}$	σ_η	$1.05^{(a)}$
θ_0	-5	θ_1	$0.01^{(a)}$
$\sigma_{CF,1yr-2yrs}$	0.05	$\sigma_{CF,5yrs}$	0.05

Note: The superscript (a) indicates those parameters estimated by maximum-likelihood; the other parameters are calibrated. σ_ε is the standard deviation of the innovations to the long-run component, see equation (19). σ_η is the standard deviation of the innovations to the cyclical component, see equation (20). $\sigma_{CF,1yr-2yrs}$ is the standard deviation of the measurement errors associated with consensus forecasts of horizons of 1 to 2 years. $\sigma_{CF,5yrs}$ is the standard deviation of the measurement errors associated with consensus forecasts of 5-year horizons.

Figure 14 displays the 12-month ahead forecast resulting from the Kalman-filter-based approach (with SPFs) together with the SECO index on expected price developments (the latter is rescaled in order to match the mean and variance of the former). The correlation between the two series is of 75%.

B.5 Adaptive expectations

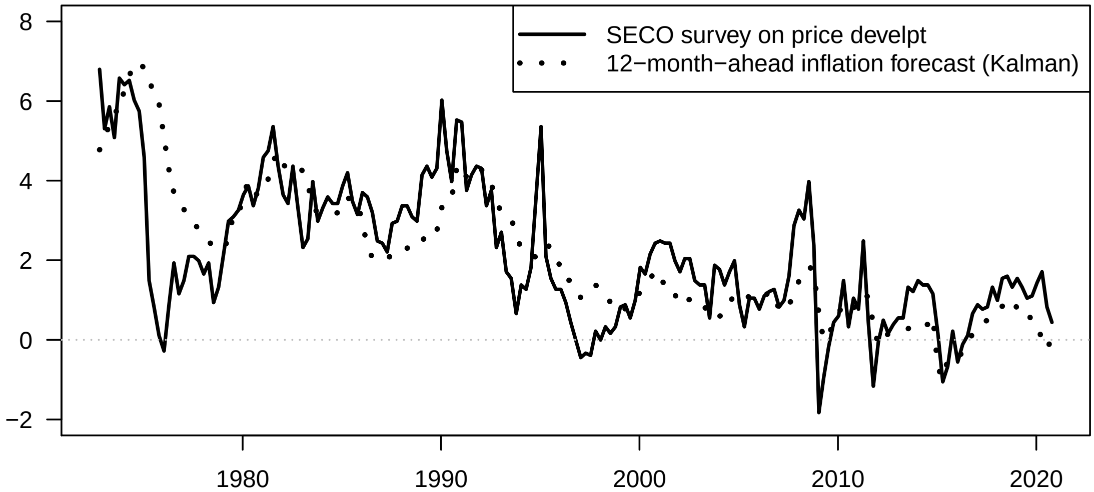
In the present appendix, we present the results obtained from a simpler approach, based on the adaptative—or error-learning—hypothesis. It relies on the assumption that agents revise their inflation expectations based on the error in their expectations for the current period (see e.g. Curtin, 2009, for a review of related approaches). In that type of approach, often used in the literature, inflation expectations are given by:

$$\mathbb{E}_t^a(\pi_{t+1}) = \mathbb{E}_{t-1}^a(\pi_t) + \gamma\big[\pi_t - \mathbb{E}_{t-1}^a(\pi_t)\big], \tag{26}$$

where γ denotes the speed of learning adjustment. By iterating, it comes that:

$$\mathbb{E}_t^a(\pi_{t+1}) = \gamma\big[\pi_t + (1-\gamma)\pi_{t-1} + (1-\gamma)^2\pi_{t-2} + \dots\big]. \tag{27}$$

Figure 14: One-year ahead forecast and SECO index on expected price developments



This figure displays the 12-month ahead forecast resulting from the Kalman-filter-based approach (with SPFs) together with the SECO index on expected price developments. The latter is rescaled in order to match the mean and variance of the former.

For horizon h, it is assumed that:

$$\begin{aligned}\mathbb{E}^a_t(\pi_{t+h}) &= \frac{1}{h}\left(\mathbb{E}^a_{t-1}(\pi_{t+h-1}) + \dots + \mathbb{E}^a_{t-h}(\pi_t)\right) + \\ &\quad \frac{\gamma}{h}\left(\left[\pi_t - \mathbb{E}^a_{t-h}(\pi_t)\right] + \dots + \left[\pi_{t-h+1} - \mathbb{E}^a_{t-2h-1}(\pi_{t-h+1})\right]\right).\end{aligned}$$

Using the lag operator L, that is such that $L\pi_t = \pi_{t-1}$, and using the notation $a_{t,h} = \mathbb{E}^a_t(\pi_{t+h})$, the previous equation rewrites:

$$\left(1 - \frac{1}{h}(L + \dots + L^h) + \frac{\gamma}{h}(L^h + \dots + L^{2h-1})\right) a_{t,h} = \frac{\gamma}{h}(1 + L + L^2 + \dots + L^{h-1})\pi_t,$$

or

$$\begin{aligned}a_{t,h} &= \frac{\gamma}{h}\left(1 - \frac{1}{h}(L + \dots + l^h) + \frac{\gamma}{h}(L^h + \dots + L^{2h-1})\right)^{-1} \times \\ &\quad (1 + L + L^2 + \dots + L^{h-1})\pi_t,\end{aligned}$$

from which we can derive a sequence of weights $\{\omega_{h,i}(\gamma)\}$ (that depend on γ) and are such that:

$$\mathbb{E}^a_t(\pi_{t+h}) = \sum_{i=0}^{\infty} \omega_{h,i}(\gamma)\pi_{t-i}.$$

In practice, we truncate this series of weights normalize them in such a way that the truncated sum equals one (since $\sum_{i=0}^{\infty} \omega_{h,i}(\gamma) = 1$).

Inflation expectations based on this adaptive approach are given in Figure 17 (Appendix F). This figure suggests the adaptive approach often results in expected inflation rates that are distant from survey-based forecasts (with deviations often larger than 100 basis points). Such proxies of inflation expectations are therefore less reliable than those resulting from the Kalman-filter-based approach.

C Panel Regression of Real Interest Rates

This Appendix presents the regressions used to produce Figure 5. Table 10 shows three examples of panel regressions to explain real interest rates. The annual panel includes the 17 countries considered in the paper for the period 1950-2019. For the first two columns, the dependent variable is the 10-year real yield computed in Section 2. In the last column, the dependent variable is the difference between the country real yield and the global yield computed as a GDP-weighted average of the 17 countries real yields. Each regression includes a country fixed effect. Most of the data comes from the JST data base and has been updated with OECD (government expenditure and debt) or IMF (investment and real GDP growth) Economic Outlook data. Life expectancy comes from ourworldindata.org.

Comparing columns 1 and 2, we see that adding the global interest rates decreases the absolute value of all coefficients and makes some of them insignificant. This also makes the R^2 much higher. Column 3 gives parameter estimates that are similar to column 2: by substracting r_t^w from r_t in column 3 we basically impose a coefficient of 1, while the estimate in column 2 is 0.907. The R^2 is quite small in this case, which shows that interest rate differentials are difficult to explain.

Table 10: Determinant of Real Interest Rates: Panel Regressions

	Dependent variable:		
	r_t		$r_t - r_t^w$
Debt/GDP	-0.010^{***}	-0.001	0.0003
	(0.004)	(0.002)	(0.002)
Government consumption/GPD	0.135^{***}	0.042^{***}	0.032^{***}
	(0.012)	(0.010)	(0.009)
Investment/GDP	0.065^{*}	-0.043	-0.054^{**}
	(0.036)	(0.027)	(0.026)
Life expectancy	-0.298^{***}	-0.109^{***}	-0.089^{***}
	(0.037)	(0.028)	(0.024)
Real GDP growth	-0.052^{**}	-0.021	-0.018
	(0.025)	(0.022)	(0.022)
Global interest rate, r_t^w		0.907^{***}	
		(0.053)	
Observations	1,178	1,178	1,178
R^2	0.227	0.515	0.041

*p<0.1; **p<0.05; ***p<0.01

Robust standard errors.

D Estimating Natural Rates of Interest

This appendix describes the approach employed to estimate natural rates of interest for 17 countries in our study. The approach is broadly based on Laubach and Williams (2003) or Holston, Laubach, and Williams (2017). It relies on a semi-structural model involving a Phillips curve (relating inflation changes to the output gap) and an Investment Saving curve (relating the output gap to interest rate gap, $r_t - r_t^*$). The equations of this model are introduced in Subsection D.1. Next, Subsection D.2 describes the matrix representation of the resulting multi-country state-space model. The Kalman filter is then used to estimate the latent variables (among which stand countries' NRIs); the estimation approach and results are presented in Subsection D.3.

D.1 Semi-structural representation of each economy

Denoting by $\pi_{t-2,4}$ the average inflation rate between dates $t-4$ and $t-2$, the Phillips curve takes the form:

$$\pi_t = b_\pi \pi_{t-1} + (1 - b_\pi)\pi_{t-2,4} + b_z z_{t-1} + \sigma_\pi \varepsilon_{\pi,t}, \tag{28}$$

where z_t is the output gap and where $\varepsilon_{\pi,t} \sim \mathcal{N}(0,1)$. Denoting by y_t and y_t^* the logarithms of GDP and potential GDP, respectively, we have:

$$y_t = y_t^* + z_t. \tag{29}$$

The Investment-Saving curve is:

$$z_t = \phi_z z_{t-1} - a_r(r_{t-1} - r_{t-1}^*) + \sigma_z \varepsilon_{z,t}, \tag{30}$$

where $\varepsilon_{z,t} \sim \mathcal{N}(0,1)$ and where $r_t - r_t^*$ is the so-called interest rate gap, defined as the yield differential between the short-term real interest rate r_t and the natural rate of interest r_t^*. Using eq. (28) to compute $\mathbb{E}_t(\pi_{t+1})$, it comes that the short-term rate interest rate is given by:

$$r_t = i_t - \mathbb{E}_t(\pi_{t+1}) = i_t - (b_\pi \pi_t + (1 - b_\pi)\pi_{t-1,4} + b_z z_t).$$

Potential GDP growth is denoted by g_t, that is $\Delta y_t^* = g_t$. This trend growth rate, that intuitively measures technological progress, features an autoregressive dynamics:

$$g_t = (1 - \phi_g)\mu_g + \phi_g g_{t-1} + \sigma_g \varepsilon_{g,t}, \tag{31}$$

where $\varepsilon_{g,t} \sim \mathcal{N}(0,1)$. In this context, (29) yields:

$$\Delta y_t = g_t + \Delta z_t. \tag{32}$$

Finally, the specification of the NRI is based on a basic optimal growth model, namely the textbook Ramsey model. Intertemporal utility maximization by the representative agent yields the following log-linear relationship between the real interest rate and the rate rate of technological change g_t, which is also the rate of growth per capita along a balanced-growth path

$$r = \delta + \theta g,$$

where θ is the relative risk aversion—which corresponds to the inverse of the intertemporal elasticity of substitution—and where δ stands for the agents' rate of time preference.

Following Laubach and Williams (2003), we assume that the latter is also time-varying, and follows an auto-regressive process or order one, that is:

$$\delta_t = (1-\phi_\delta)\delta + \phi_\delta \delta_{t-1} + \sigma_\delta \varepsilon_{\delta,t}. \tag{33}$$

Hence, the time-varying natural rate of interest is given by:

$$r_t^* = \delta_t + \theta g_t. \tag{34}$$

using what precedes, the IS curve (30) rewrites:

$$z_t = \phi_z z_{t-1} - a_r\{i_{t-1} - b_\pi \pi_{t-1} - (1-b_\pi)\pi_{t-2,4} - b_z z_{t-1} - \theta g_{t-1} - \delta_{t-1}\} + \sigma_z \varepsilon_{z,t}.$$

D.2 State-space representation of the multi-country model

For each country, the model presented in D.1 can be cast in a state-space representation, comprising measurement and transition equations. In matrix form, the measurement equations are:

$$\begin{bmatrix} \pi_t \\ \Delta y_t \end{bmatrix} = \begin{bmatrix} b_\pi \pi_{t-1} + (1-b_\pi)\pi_{t-2,4} \\ 0 \end{bmatrix} + \begin{bmatrix} 0 & b_z & 0 & 0 \\ 1 & -1 & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} z_t \\ z_{t-1} \\ g_t \\ \delta_t \end{bmatrix} + \begin{bmatrix} \sigma_\pi \\ 0 \end{bmatrix} \varepsilon_{\pi_t},$$

and the transition equations read:

$$\begin{bmatrix} z_t \\ z_{t-1} \\ g_t \\ \delta_t \end{bmatrix} = \begin{bmatrix} -a_r(i_{t-1} - b_\pi \pi_{t-1} - (1-b_\pi)\pi_{t-2,4}) \\ 0 \\ (1-\phi_g)\mu_g \\ (1-\phi_\delta)\delta \end{bmatrix} + \begin{bmatrix} \phi_z + a_r b_z & 0 & a_r\theta & a_r \\ 1 & 0 & 0 & 0 \\ 0 & 0 & \phi_g & 0 \\ 0 & 0 & 0 & \rho_\delta \end{bmatrix} \cdot \begin{bmatrix} z_{t-1} \\ z_{t-2} \\ g_{t-1} \\ \delta_{t-1} \end{bmatrix} + \begin{bmatrix} \sigma_z & 0 & 0 \\ 0 & 0 & 0 \\ 0 & \sigma_g & 0 \\ 0 & 0 & \sigma_\delta \end{bmatrix} \cdot \begin{bmatrix} \varepsilon_{z,t} \\ \varepsilon_{g,t} \\ \varepsilon_{\delta,t} \end{bmatrix}.$$

$$\begin{aligned} Y_{j,t} &= \mu_{j,t} + G\beta_{j,t} + M\varepsilon_{\pi,j,t} \\ \beta_{j,t} &= \nu_{j,t} + H\beta_{j,t-1} + N \begin{bmatrix} \varepsilon_{z,t} \\ \varepsilon_{g,t} \\ \varepsilon_{\delta,t} \end{bmatrix} \end{aligned}$$

We assume that, for $k \in \{\pi, z, g, \delta\}$,

$$\mathbb{V}ar(\varepsilon_{k,t}) = \Sigma_k \Sigma_k'.$$

(correlation matrix since the ε_t's have unit variance). Then, if we define $\epsilon_{k,t} = \Sigma_k^{-1}\varepsilon_{k,t}$, we have:

$$\varepsilon_{k,t} = \Sigma_k \epsilon_{k,t}, \quad \epsilon_{k,t} \sim \mathcal{N}(0, \mathbf{Id}_N).$$

Define
$Y_t = [\pi_{1,t}, \ldots \pi_{N,t}, \Delta y_{1,t}, \ldots, \Delta y_{N,t}]'$

$\beta_t = [z_{1,t}, \dots z_{N,t}, z_{1,t-1}, \dots z_{N,t-1}, g_{1,t}, \dots g_{N,t}, r^*_{1,t}, \dots r^*_{N,t}]'$.
The vectorial measurement and transition equations are then respectively given by:

$$Y_t = \mu_t + [G \otimes \mathbf{Id}_N]\beta_{j,t} + [M \otimes \mathbf{Id}_N]\Sigma_\pi \epsilon_{\pi,j,t} \quad (35)$$

$$\beta_t = \nu_t + [H \otimes \mathbf{Id}_N]\beta_{j,t-1} + [N \otimes \mathbf{Id}_N] \begin{bmatrix} \Sigma_z & 0 & 0 \\ 0 & \Sigma_g & 0 \\ 0 & 0 & \Sigma_\delta \end{bmatrix} \begin{bmatrix} \epsilon_{z,t} \\ \epsilon_{g,t} \\ \epsilon_{\delta,t} \end{bmatrix}. \quad (36)$$

D.3 Estimation approach and results

The model parameterization is estimated by maximizing the likelihood function associated with the sate-space system (35)-(36)—the likelihood function being a by-product of the Kalman filter algorithm.

It is well-known that it is difficult to precisely estimate natural rates of interest in the context of these models (e.g. Fiorentini et al., 2018). In order to improve the accuracy of the parameter estimates, we assume that the latter are the same across the same 17 countries as in the Jordà, Schularick, and Taylor (2015)'s database (see Subsection 2.2.1).[34] In order to reduce the number of parameters to be estimated, and in order to obtain reasonable estimates of output gaps and natural rates of interest, we calibrate some parameters as follows:

- Following the standard approach, we assume that the trend potential growth rates (g_t) and the rates of time preference (δ_t) are highly persistent and, accordingly, set ρ_g and ρ_δ to 0.999.
- The standard deviations of the shocks associated with these two variables (g_t and δ_t) being significantly challenging to estimate, we fix their values in such a way that the unconditional standard deviations of g_t and δ_t amount to 1 percentage point.
- We assume that half of the inflation expectations results from the moving average component $\pi_{t-2,4}$, the remaining half being based on the last-observed inflation rate π_{t-1} (see eq. 28). That is $b_\pi = 0.5$.
- We assume that the unconditional averages of δ_t and of g_t (μ_δ and μ_g) are respectively equal to 1% (annually) and to the cross-country average of GDP growth rates. Note that given the high persistence of these processes, the values of these two averages only mildly affect the results.

Moreover, in order to allow for different sizes of shocks during the COVID19 period, we allow for changes in σ_z and σ_π starting in 2020Q1. Table 11 reports the resulting parameter estimates.

Figure 15 compares long-term real rates computed in Section 2, the trend real rates obtained in 4.1 and the Natural Rates of Interest. This figure also shows the 95% confidence intervals associated with these different measures of real rates. It appears that the real rates proposed in Section 2 are substantially less uncertain than the two measures of

[34] We do not use the (annual) JST data here. Instead we employ (quarterly) data extracted from the OECD Economic Outlook database for short-term nominal rates and GDP, and from the IMF IFS database for consumer price indices (on which are based inflation rates). German short-term nominal rates are available only from 1991 onwards; also, in order to start the estimation in the early 80s, we extend the German series of short-term rate backwards, using data from the Area-Wide Model database of Fagan et al. (2001).

Table 11: Parameterization

Phillips curve eq. (28)		IS curve eq. (30)		Potential growth eq. (31)		NRI, r^* eqs. (33) and (34)	
Param.	**Value**	**Param.**	**Value**	**Param.**	**Value**	**Param.**	**Value**
b_π	0.500	ϕ_z	0.946 (0.054)	$\mu_g\,(\times 10^2)$	0.471	δ	0.010
b_z	0.015 (0.008)	a_r	0.249 (0.240)	ϕ_g	0.999	ϕ_δ	0.999
$\sigma_\pi\,(\times 10^2)$	0.204 (0.010)	$\sigma_z\,(\times 10^2)$	0.729 (0.052)	$\sigma_g\,(\times 10^2)$	0.045	$\sigma_\delta\,(\times 10^2)$	0.999
$\sigma_{\pi,covid}\,(\times 10^2)$	0.000 (0.163)	$\sigma_{z,covid}\,(\times 10^2)$	7.182 (7.064)			θ	3.712 (1.759)

Note: This table shows the calibration of the state-space model used to estimate natural rates of interest of 17 countries of the Jordà, Schularick, and Taylor (2015)'s database (see Subsection 2.2.1). Standard deviations (in parentheses) are based on the outer-product approximation of the covariance matrix of parameter estimates. $\sigma_{z,covid}$ and $\sigma_{\pi,covid}$ are the values taken by σ_z and σ_π in 2020.

equilibrium interest rates computed in 4.1 and in the present subsection. The differences in accuracy are particularly marked since the late 80s (i.e., since survey-based inflation forecasts are available).

E The Effect of the Supply of Public Debt over Time and across Maturities

This appendix examines the persistence of the effect of Swiss public debt issuance on convenience yields and its effect across different maturities.

Our results in column (4) of Table 6 show the effect of a *change* in Swiss public debt. This implies that the identified effect is not necessarily long-lasting. In Table 16 in the Appendix, we show the results when we estimate the effect of the *level* of public debt. When we do not use IV regressions and do not control for the quadratic trend, the coefficient of the Swiss public debt is positive, which probably arise from a positive bias due to demand shocks. When we introduce the quadratic trend and use the IV method, the coefficient becomes significantly negative, which suggests that the effect of public debt is persistent.

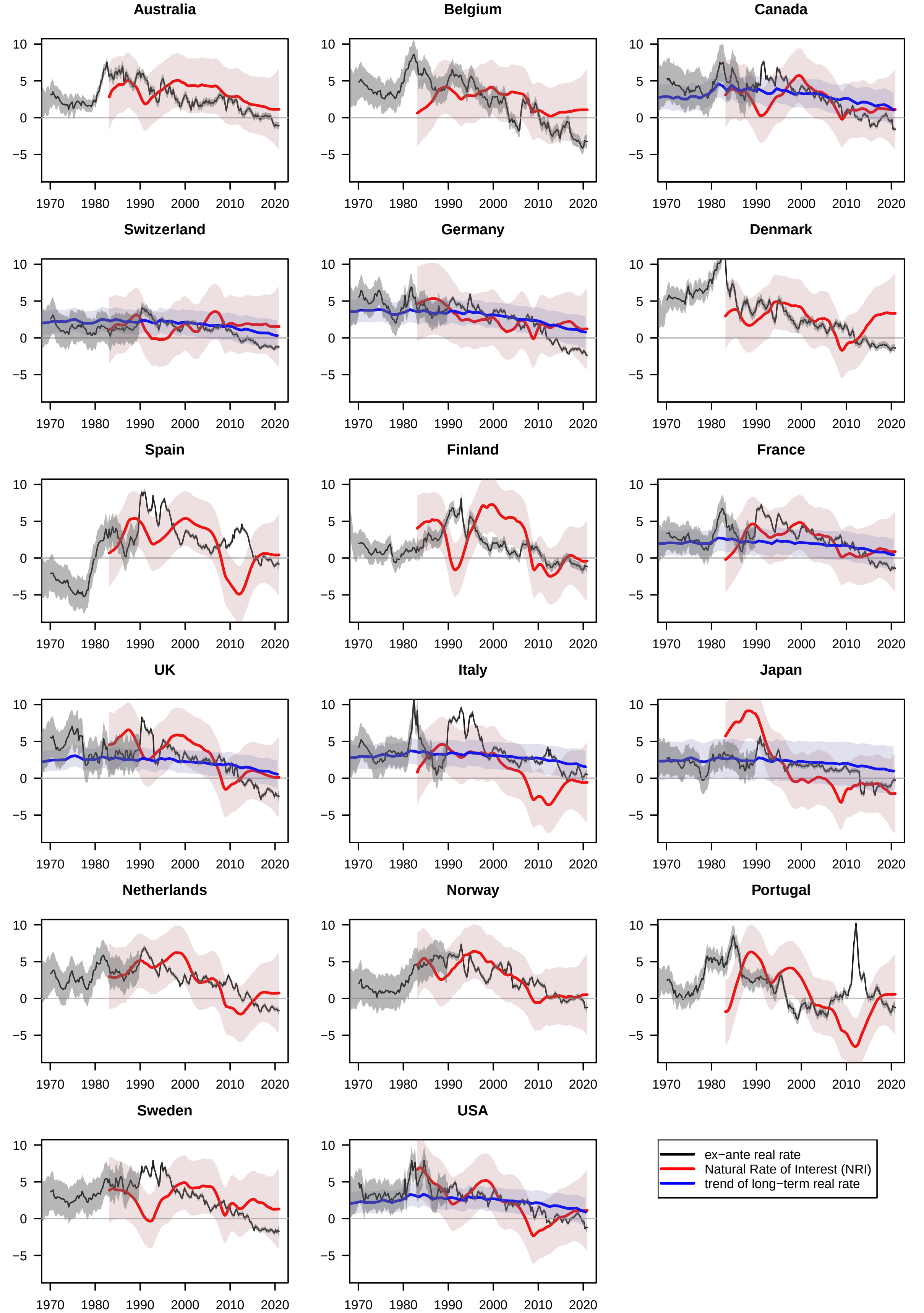
To determine how persistent the effect of public debt on the convenience yield is, depending on the maturity, we estimate the following regressions:

$$\lambda_{t+k,h,i} = \beta_1 \Delta \left(\frac{\text{Debt net of CB}}{GDP} \right)_{CH,t} + \beta_2 X_{t,CH} + \beta_3 X_{t,i} + \beta_4 X_t + \alpha_i + \epsilon_{it} \qquad (37)$$

for $k = 0$, 1, 2 and 3 quarters and $h = 3$ months, 1, 3, 5, 7 and 10 years. $X_{t,CH}$, $X_{t,i}$ and X_t correspond to the same Swiss, foreign and time-specific variables as in equation (13). The results are shown in Table 12.

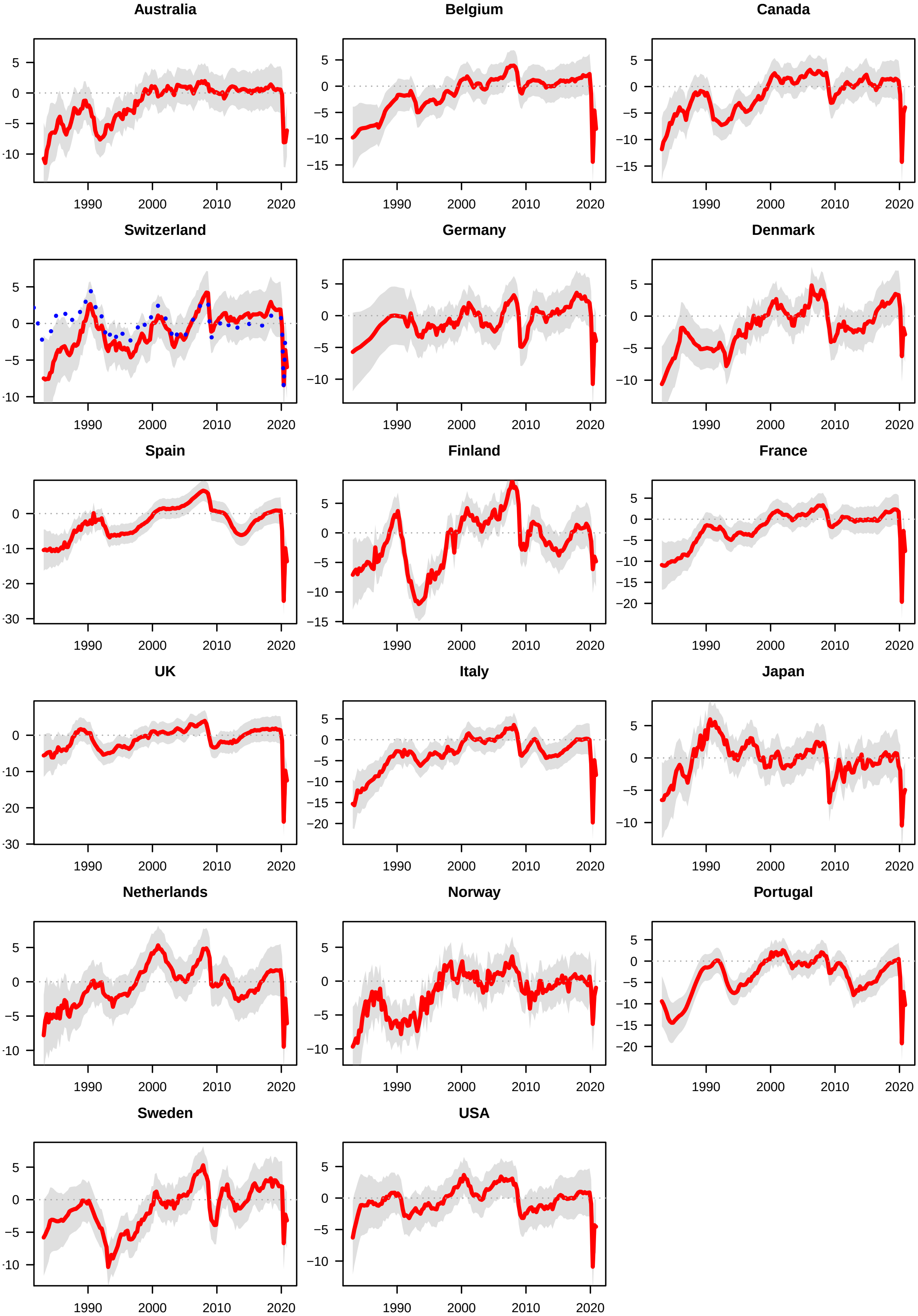
For all maturities, the impact effect is very strong and of the same order of magnitude (-20 to -40 basis points for an increase of public debt equivalent to 1% GDP). The effect is very persistent for the maturities of 7 and 10 years. For maturities of 5, 3 and 1 years, the negative effect lasts for 2 to 3 quarters (beyond 3 quarters, the effect stays negative but becomes insignificant, with a few exceptions). The vanishing effect of public debt could be explained by the crowding-in or crowding-out of safe assets that are close substitutes to

Figure 15: Comparison of equilibrium real rates



This figure displays long-term (10-year) real rates computed in Section 2, the long-term real-rate trends ($\overline{R}_{i,t}$) obtained in 4.1 and the Natural Rate of Interests discussed in 4.2. The shaded areas correspond to 95% confidence intervals.

Figure 16: Estimated output gaps



This figure displays the output gap estimates (z_t) stemming from the NRI estimation approach. See Appendix D for details regarding the estimation. For Switzerland, the blue dotted line is the SECO's estimate of the output gap, see https://www.seco.admin.ch/seco/en/home/wirtschaftslage---wirtschaftspolitik/Wirtschaftslage/potenzialwachstum.html.

Table 12: The effect of the supply of public debt on convenience yields - Different horizons and different maturities

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	$\eta_{t,h,j}$	$\eta_{t+1,h,j}$	$\eta_{t+2,h,j}$	$\eta_{t+3,h,j}$	$\eta_{t+4,h,j}$	$\eta_{t+5,h,j}$	$\eta_{t+6,h,j}$
$h = 10y$	-32.90***	-29.76***	-30.34***	-22.49***	-31.55***	-25.43***	-25.62***
	(7.41)	(2.87)	(6.14)	(4.62)	(6.48)	(4.66)	(7.15)
$h = 7y$	-26.26***	-25.93***	-30.39***	-16.43***	-24.25***	-20.74***	-16.89***
	(7.61)	(3.01)	(5.78)	(4.77)	(6.12)	(5.35)	(6.32)
$h = 5y$	-23.95***	-23.38***	-25.76***	-6.55	-12.10**	-18.47***	-8.15
	(7.64)	(3.24)	(5.60)	(5.61)	(5.81)	(6.17)	(6.22)
$h = 3y$	-27.47***	-35.81***	-22.98***	-8.26*	-15.02***	-13.60**	-12.23**
	(6.90)	(3.91)	(4.70)	(4.90)	(5.57)	(6.22)	(6.08)
$h = 2y$	-25.84***	-29.66***	-18.79***	-6.91	-16.18***	-7.81	-15.58***
	(6.57)	(3.78)	(4.63)	(5.11)	(5.16)	(5.40)	(6.04)
$h = 1y$	-31.85***	-35.62***	-5.55	-6.91	-42.37***	-16.83***	-22.03***
	(7.30)	(4.42)	(5.34)	(5.06)	(9.69)	(5.48)	(7.65)
$h = 3m$	-31.19***	-20.31***	21.43***	0.46	1.61	15.71***	9.57
	(8.12)	(5.10)	(5.55)	(6.67)	(7.60)	(5.09)	(7.46)

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Note: The dependent variable is the convenience yield of Swiss government debt vis-à-vis country i's government debt, in basis points, at maturity h, and horizon $t + k$, i.e. $\lambda_{t+k,h}$. Government debts are the quarterly changes in the ratio of government debt net of central bank holdings to GDP, in percentage points. The specifications of the regressions follow equation (13), only the dependent variables changes. We report only the coefficients of the Swiss public debt.

public debt (Kacperczyk et al., 2021) for some maturities. Suppose that the government issues public debt, which, as we have shown, decreases the Swiss convenience yield. The relatively low price of Swiss safe assets becomes then a deterrent to the production of safe assets by the private sector. This mechanism contributes to re-inflating the price of safe assets in the medium run, which eventually increases the Swiss convenience yield, thus offsetting the initial effect. This offsetting effect takes 6 to 9 months to kick in.

For maturities of 3 months, the negative effect lasts for 2 quarters and then turns positive in the third quarter. However, bear in mind that our instrument is based on the issuance of long-term bonds. When the government issues long-term bonds, bonds with short-term maturities become relatively scarcer, which increases their convenience yield. This effect is consistent with a demand for bonds driven by the“preferred habitat” of investors.

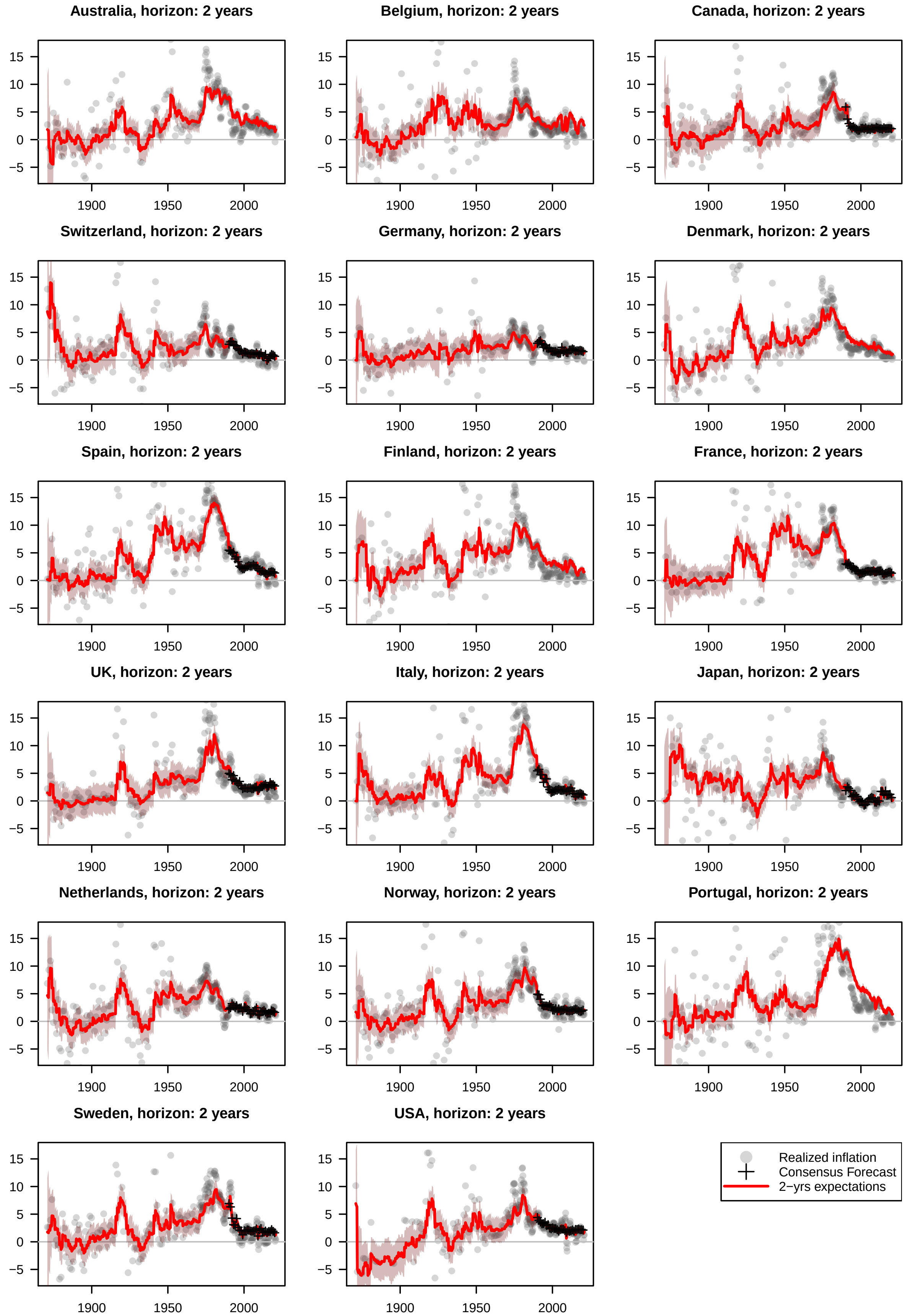
F Additional charts and tables

Table 13: First years on which nominal yields data become available

Country	Refinitiv					JST	
	3M	**1Y**	**2Y**	**5Y**	**10Y**	**3M**	**10Y**
Australia	2010	1995	1976	1976	1976	1870	1870
Belgium	2005	2005	2005	2005	1990	1870	1870
Canada	1987	1994	1986	1986	1986	1934	1870
Switzerland	1994	1996	1995	1994	1994	1870	1880
Germany	1995	1994	1980	1986	1970	1870	1870
Denmark	1995	1995	1982	1983	1983	1875	1870
Spain	2011	2011	1988	1988	1991	1870	1870
Finland	–	–	1992	1992	1991	1870	1870
France	1989	1995	1989	1989	1986	1870	1870
UK	1975	1995	1991	1987	1979	1870	1870
Italy	1982	2009	1989	1989	1991	1870	1870
Japan	1994	1995	1979	1986	1970	1879	1870
Netherlands	2011	1995	1993	1994	1987	1870	1870
Norway	1993	1995	1994	1993	1987	1870	1870
Portugal	2012	2009	1994	1995	1994	1880	1870
Sweden	1983	1984	1986	1985	1987	1870	1870
USA	1970	1970	1976	1970	1970	1870	1870

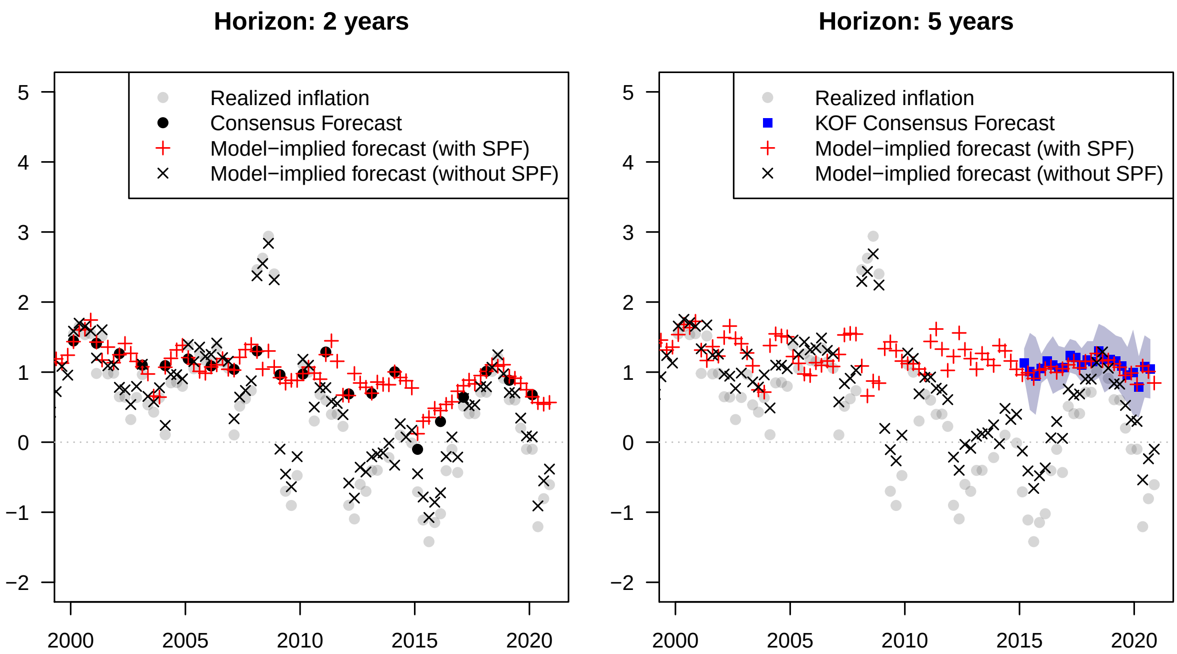
Note: This table reports the years on which the different times series of nominal yields start. JST refers to Jordà et al. (2015).

Figure 17: 2-year inflation expectations



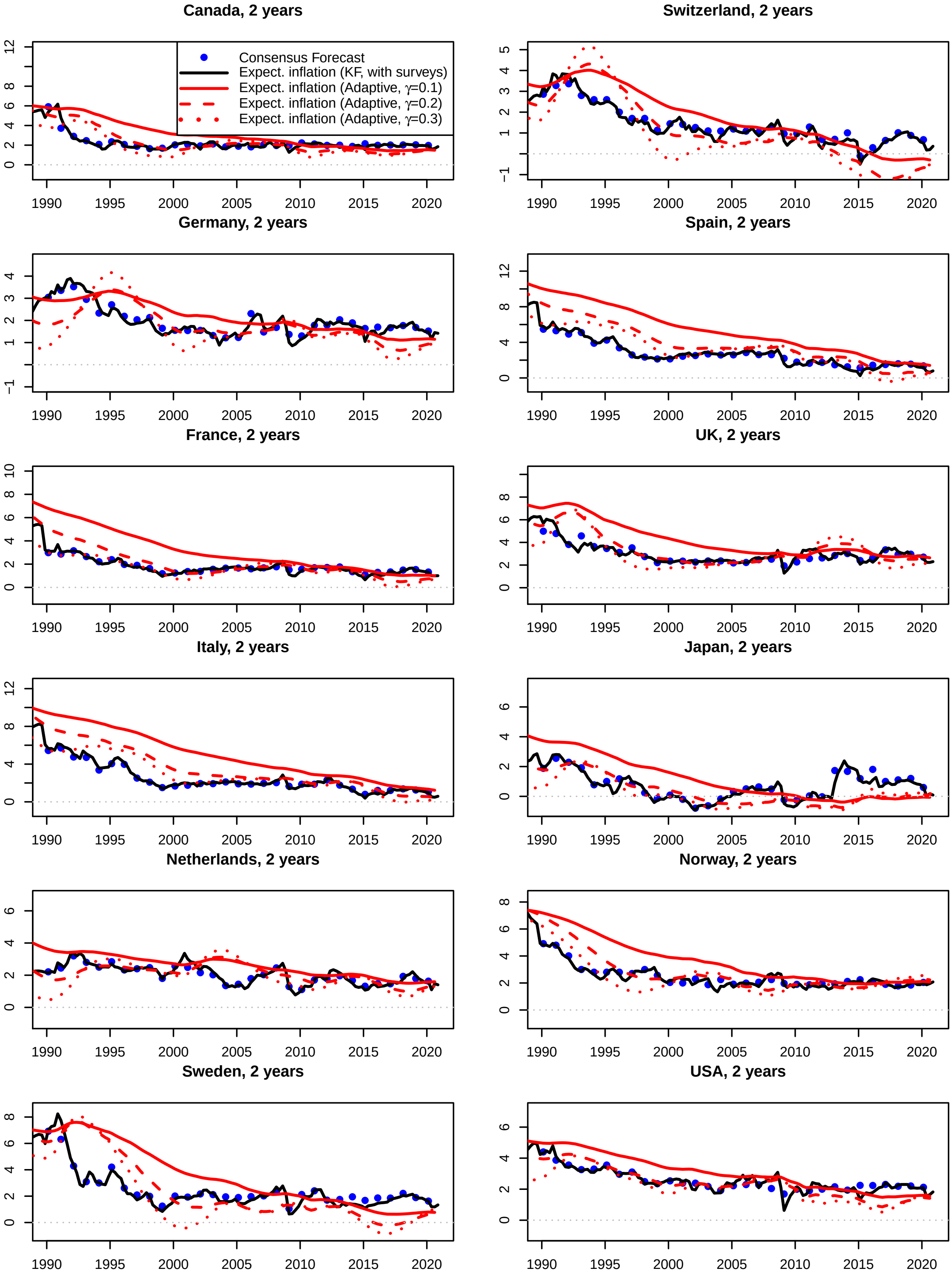
This figure displays 2-year inflation expectations. Our estimates are in red. The grey-shaded area surrounding the red line corresponds to a ±2 standard-deviation band reflecting the uncertainty stemming from the Kalman filtering technique. The black crosses are survey-based 2-year forecasts produced by professional forecasters. Grey dots are realized inflation rates.

Figure 18: The importance of using survey-based forecasts (Switzerland)



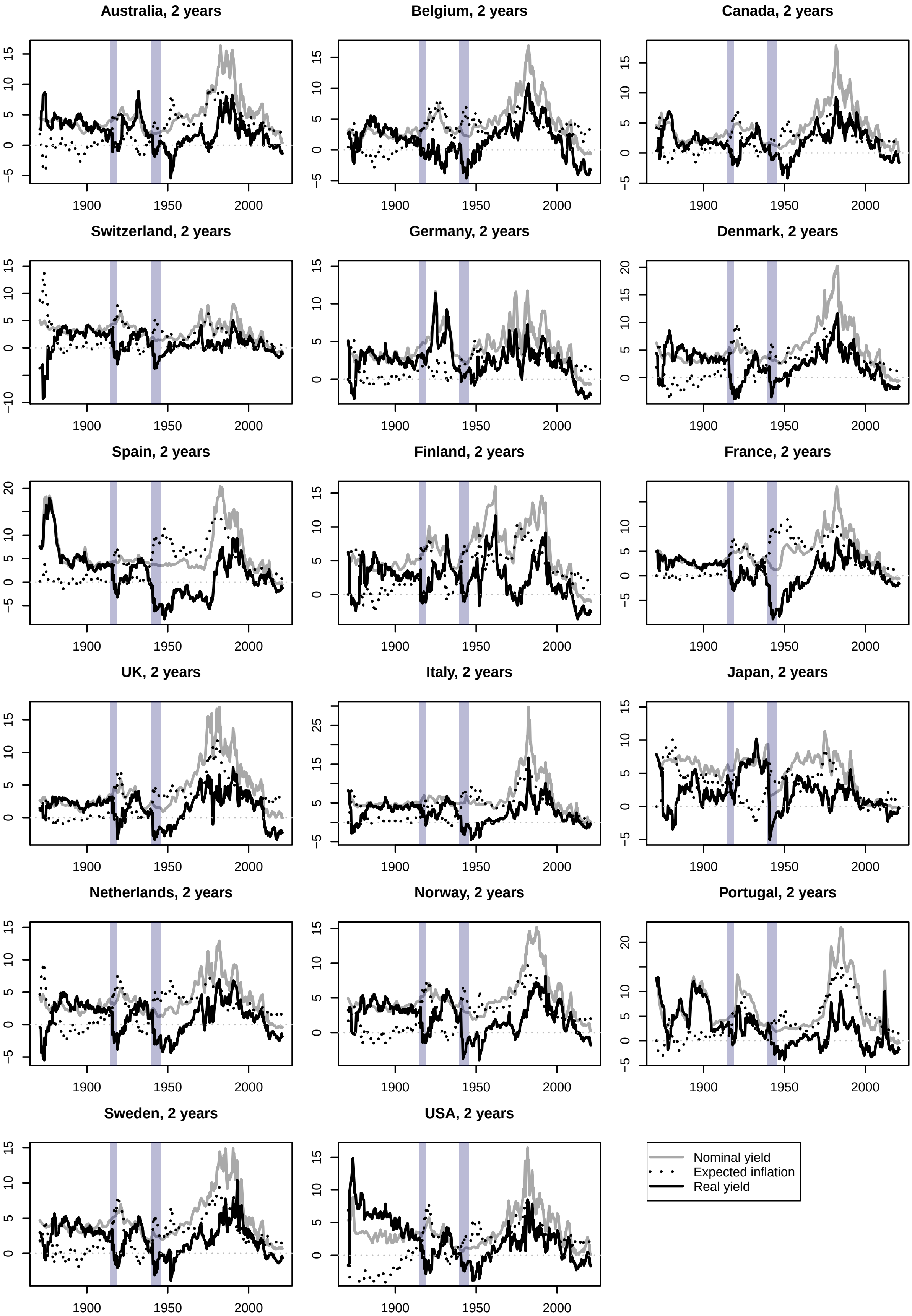
This figure shows the two bottom plots of Figure 1, to which we add the model-implied forecasts that would be obtained if the approach was not involving surveys of professional forecasters (black crosses). In the latter case, model-implied inflation expectations would then be far from professional forecasts.

Figure 19: 2-year inflation expectations



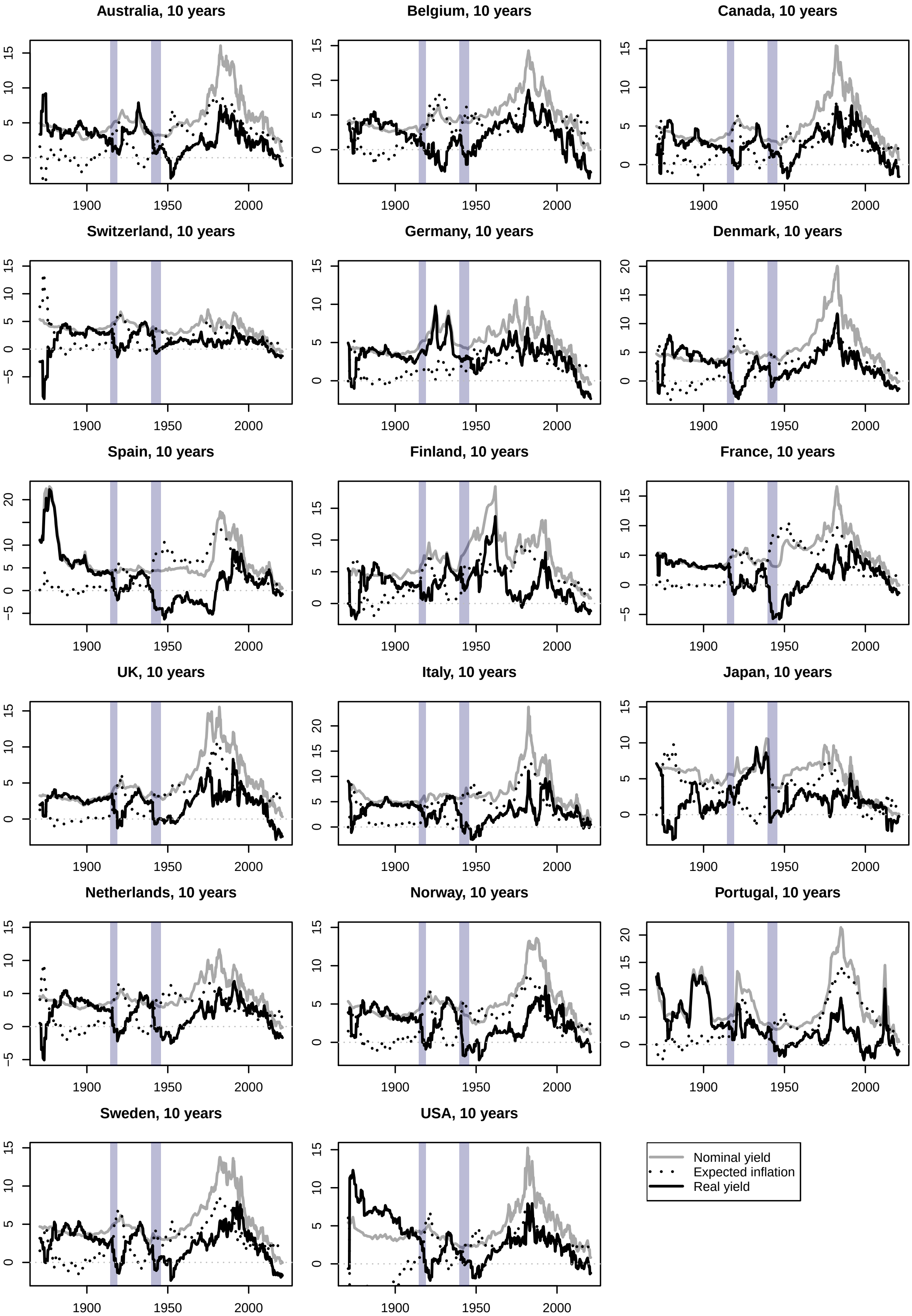
This figure compares different measures of 2-year inflation expectations. The consensus forecasts are represented in blue. The black solid line shows the inflation expectations resulting from our Kalman-filter approach (involving surveys). The red lines correspond to expectations stemming from the adaptive approach, for different values of γ (see end of Subsection 2.2.3 and Appendix B.5).

Figure 20: 2-year interest rates decomposition



This figure shows the decomposition of government nominal yields into two components: the real rate and the inflation expectation part (see equation 1). The computation (extrapolation) of nominal yields and inflation expectations are detailed in 2.2.2 and 2.2.3, respectively. Vertical grey-shaded areas indicate the two world wars.

Figure 21: 10-year interest rates decomposition



This figure shows the decomposition of government nominal yields into two components: the real rate and the inflation expectation part (see equation 1). The computation (extrapolation) of nominal yields and inflation expectations are detailed in 2.2.2 and 2.2.3, respectively. Vertical grey-shaded areas indicate the two world wars.

Table 14: Descriptive statistics of 2-year yields

		CHE	AUS	BEL	CAN	DEU	DNK	ESP	FIN	FRA	GBR	ITA	JPN	NLD	NOR	PRT	SWE	USA
Nominal yields, 2-year maturity																		
1880-2020	avg.	**2.9**	4.9	4.4	4.0	4.3	5.3	5.3	6.2	4.4	4.4	6.2	5.0	3.7	4.9	6.4	4.7	3.7
	s.d.	**1.6**	3.0	3.1	3.1	2.4	3.8	3.9	3.5	3.3	3.6	4.3	2.7	2.5	2.9	4.8	3.0	2.6
	vol.	**27.5**	41.8	33.4	40.3	41.3	42.4	44.6	41.0	37.0	48.9	62.2	34.8	34.2	31.2	53.5	43.7	55.4
	IQ	**2.1**	2.4	2.9	2.9	2.7	2.7	1.3	4.5	3.4	3.7	1.8	3.6	2.3	2.3	6.5	2.6	2.7
1880-1970	avg.	**3.0**	3.6	3.6	2.9	4.2	4.3	4.3	6.4	3.6	3.0	5.0	6.0	3.0	4.0	5.4	3.8	2.8
	s.d.	**1.1**	1.1	1.3	1.4	1.8	1.4	1.2	2.7	1.6	1.7	0.7	1.5	1.3	1.0	3.0	1.2	1.2
	vol.	**13.4**	12.9	15.7	14.5	25.3	13.3	17.6	29.9	16.0	16.3	17.4	27.6	16.0	11.9	28.5	12.3	21.4
	IQ	**1.8**	1.9	1.5	2.0	2.0	1.6	0.9	3.8	2.4	2.1	0.9	1.7	1.3	1.1	4.2	1.3	1.5
1970-2020	avg.	**2.9**	7.2	6.1	6.1	4.5	7.1	7.0	5.8	6.0	7.0	8.4	3.3	5.0	6.6	8.3	6.5	5.3
	s.d.	**2.4**	3.9	4.5	4.0	3.2	5.6	5.9	4.6	4.7	4.7	6.6	3.4	3.5	4.1	6.5	4.3	3.6
	vol.	**42.2**	67.7	51.4	64.5	60.5	68.3	70.7	55.3	57.8	78.5	101.4	44.8	52.8	49.5	80.7	70.9	88.5
	IQ	**3.7**	5.0	6.9	6.0	4.6	8.3	9.6	7.6	7.1	6.9	10.6	6.5	5.4	6.6	11.7	7.6	5.6
Real yields, 2-year maturity																		
1880-2020	avg.	**1.1**	2.0	1.5	1.7	2.5	2.3	1.1	2.5	0.7	1.5	2.6	2.1	1.3	2.2	2.2	2.1	1.9
	s.d.	**1.6**	2.2	2.9	2.1	2.1	2.7	3.8	2.7	3.0	2.3	2.7	2.5	2.4	2.3	3.5	2.1	2.7
	vol.	**46.4**	58.5	59.3	51.5	50.7	60.3	64.2	67.1	59.5	58.4	76.2	61.4	50.7	53.6	73.0	59.9	67.1
	IQ	**2.5**	3.0	3.8	2.8	2.1	3.5	5.6	3.1	3.9	2.9	3.6	3.0	3.7	3.2	4.5	3.2	4.0
1880-1970	avg.	**1.3**	2.0	1.2	1.2	2.9	2.1	0.9	3.3	0.0	1.2	2.2	2.7	1.0	2.0	2.9	1.9	2.0
	s.d.	**1.7**	2.1	2.2	1.8	1.9	2.2	3.9	2.1	3.0	1.8	2.4	2.7	2.3	2.2	3.5	2.0	2.9
	vol.	**49.5**	54.5	61.3	45.4	47.9	58.8	60.5	73.0	62.2	46.4	59.9	69.5	51.5	56.3	65.0	54.8	55.8
	IQ	**2.5**	2.9	3.3	2.2	1.8	2.8	6.1	1.8	3.9	2.5	3.4	3.2	3.9	2.9	4.4	3.1	4.6
1970-2020	avg.	**0.6**	2.2	2.3	2.6	2.0	2.8	1.3	1.0	2.1	2.2	3.2	0.9	1.8	2.4	1.0	2.4	1.8
	s.d.	**1.3**	2.2	3.7	2.4	2.4	3.3	3.5	2.9	2.4	2.8	3.1	1.4	2.4	2.5	3.1	2.3	2.2
	vol.	**40.1**	65.1	55.2	61.0	55.7	62.9	70.0	54.7	54.2	75.4	98.8	43.3	49.0	49.4	85.3	68.2	84.5
	IQ	**1.4**	3.1	6.0	3.5	2.9	5.0	5.1	3.1	2.8	3.8	4.3	2.1	3.2	4.4	4.7	3.2	3.2

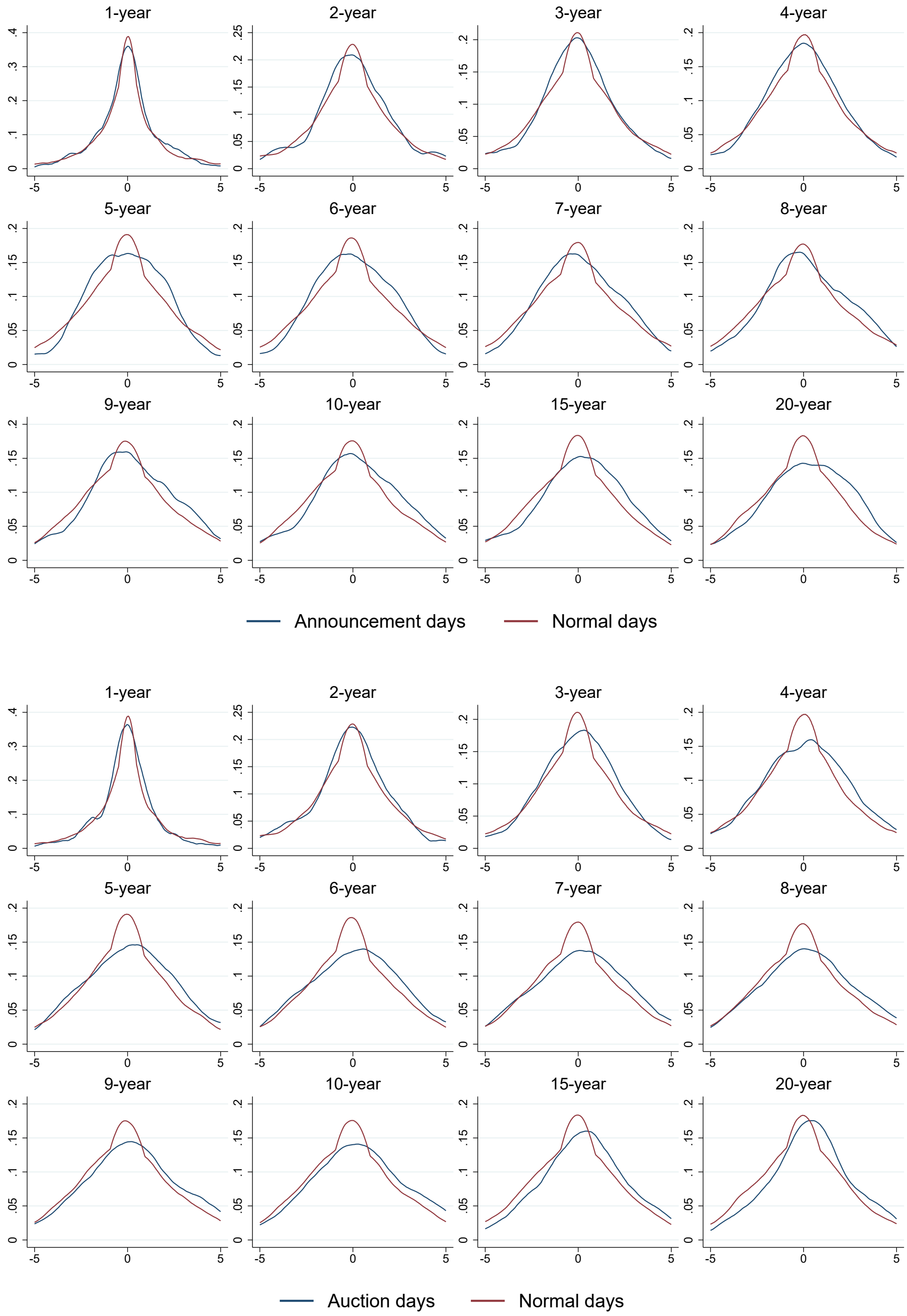
Note: This table reports descriptive statistics for 2-year yields. “avg.” stands for “average”; “s.d.” stands for “standard deviation”; “vol.” stands for “volatility”, it is defined as the standard deviation of the changes in the interest rates, expressed in basis points; “IQ” stands for “inter-quartile”, i.e. the difference between the 75th and the 25th quantiles. CHE: Switzerland, AUS: Australia, BEL: Belgium, CAN: Canada, DEU: Germany, DNK: Denmark, ESP: Spain, FIN: Finland, FRA: France, GBR: U.K., ITA: Italy, JPN: Japan, NLD: Netherlands, NOR: Norway, PRT: Portugal, SWE: Sweden, USA: United States of America.

Table 15: Descriptive statistics of 5-year yields

		CHE	AUS	BEL	CAN	DEU	DNK	ESP	FIN	FRA	GBR	ITA	JPN	NLD	NOR	PRT	SWE	USA
Nominal yields, 5-year maturity																		
1880-2020	avg.	**3.3**	5.1	4.6	4.5	4.8	5.4	5.5	6.7	4.9	4.7	6.5	4.7	4.0	4.8	6.9	4.7	3.9
	s.d.	**1.5**	3.0	2.9	2.9	2.3	3.9	3.7	3.6	3.1	3.5	3.9	2.5	2.4	2.8	4.9	3.0	2.6
	vol.	**23.1**	38.3	30.7	36.1	36.7	39.6	43.1	41.2	33.8	40.7	53.1	33.8	29.8	28.9	54.6	36.3	47.1
	IQ	**1.7**	2.6	2.8	2.8	3.0	2.7	1.5	5.4	3.6	3.5	1.6	2.9	2.2	2.4	6.7	2.5	2.3
1880-1970	avg.	**3.3**	3.8	3.7	3.4	4.7	4.2	4.7	7.0	4.1	3.3	5.4	5.3	3.4	3.8	5.8	3.7	2.9
	s.d.	**0.9**	1.1	1.3	1.3	1.7	1.5	1.8	3.6	1.6	1.6	0.7	1.5	1.1	1.0	3.4	1.1	1.0
	vol.	**10.9**	12.2	13.5	11.1	20.7	11.4	20.9	32.1	13.6	11.7	15.4	26.6	11.6	11.2	33.3	9.6	14.3
	IQ	**1.1**	1.8	1.8	1.8	2.5	1.5	0.9	5.1	2.8	1.9	1.0	1.8	1.0	1.6	4.5	1.2	1.1
1970-2020	avg.	**3.2**	7.4	6.2	6.5	5.0	7.5	7.0	6.2	6.4	7.3	8.6	3.5	5.3	6.6	8.8	6.7	5.8
	s.d.	**2.2**	3.9	4.1	3.9	3.2	5.7	5.4	3.7	4.5	4.5	6.0	3.3	3.4	3.9	6.3	4.2	3.4
	vol.	**35.6**	61.9	47.8	58.4	54.9	64.2	66.2	53.6	53.3	66.0	86.4	43.7	47.0	46.0	79.4	59.0	76.7
	IQ	**3.3**	5.0	5.9	5.7	4.6	8.0	8.9	6.5	6.6	6.6	10.0	6.3	5.2	5.5	11.2	7.2	5.1
Real yields, 5-year maturity																		
1880-2020	avg.	**1.4**	2.3	1.7	2.1	3.0	2.4	1.4	3.0	1.2	1.9	2.9	1.7	1.7	2.1	2.7	2.1	2.2
	s.d.	**1.4**	2.0	2.7	2.0	2.0	2.7	4.0	2.7	2.7	2.1	2.5	2.4	2.2	2.1	3.8	2.1	2.5
	vol.	**36.1**	48.6	49.7	45.5	43.5	50.4	56.3	57.6	49.2	49.8	62.6	53.2	41.9	45.2	66.0	47.1	55.2
	IQ	**1.9**	2.5	3.7	2.3	1.8	3.1	5.5	2.9	3.6	2.4	2.9	2.6	3.4	2.9	4.6	3.0	3.7
1880-1970	avg.	**1.7**	2.2	1.4	1.7	3.3	2.0	1.3	3.9	0.5	1.5	2.5	2.0	1.4	1.9	3.3	1.8	2.2
	s.d.	**1.4**	1.8	2.0	1.5	1.7	2.0	4.2	2.5	2.7	1.5	2.1	2.7	2.1	2.0	3.8	1.8	2.7
	vol.	**37.6**	41.3	47.2	35.5	37.6	44.4	49.2	60.1	47.5	35.1	46.3	56.9	40.2	43.7	56.3	41.9	42.3
	IQ	**2.0**	2.5	3.2	1.7	1.5	2.5	6.4	2.4	3.6	2.2	2.9	3.2	3.7	2.5	3.9	3.0	4.5
1970-2020	avg.	**0.9**	2.4	2.4	3.0	2.5	3.1	1.4	1.3	2.4	2.5	3.5	1.1	2.2	2.5	1.5	2.6	2.3
	s.d.	**1.3**	2.1	3.5	2.4	2.5	3.4	3.5	2.2	2.3	2.7	2.8	1.5	2.3	2.3	3.2	2.4	2.1
	vol.	**33.2**	59.5	53.6	59.2	52.7	59.6	66.8	52.7	52.1	68.7	84.3	45.7	44.6	48.7	80.3	55.3	73.6
	IQ	**1.3**	2.4	5.5	3.3	2.9	4.7	4.5	2.1	2.5	2.5	3.2	1.9	2.3	3.8	4.2	3.3	2.8

Note: This table reports descriptive statistics for 5-year yields. "avg." stands for "average"; "s.d." stands for "standard deviation"; "vol." stands for "volatility", it is defined as the standard deviation of the changes in the interest rates, expressed in basis points; "IQ" stands for "inter-quartile", i.e. the difference between the 75th and the 25th quantiles. CHE: Switzerland, AUS: Australia, BEL: Belgium, CAN: Canada, DEU: Germany, DNK: Denmark, ESP: Spain, FIN: Finland, FRA: France, GBR: U.K., ITA: Italy, JPN: Japan, NLD: Netherlands, NOR: Norway, PRT: Portugal, SWE: Sweden, USA: United States of America.

Figure 22: Bond yield returns on announcement and auction days versus normal days



This figure shows for several maturities the kernel densities of Swiss government bond yield returns on different types of days. The solid blue and red lines represent the density of these returns, in basis points, for announcement and auction days respectively. The solid green line represents bond returns on normal days, i.e., all days except announcement and auction days.

Table 16: The effect of the supply of public debt in levels on convenience yields - Debt in level

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) IV
(Debt net of CB/GDP)$_{CH}$	2.6***	-2.4***	-2.8***	-1.8***	-13***
	(.19)	(.83)	(.68)	(.64)	(3.7)
(Debt net of CB/GDP)$_j$	.57***	.58***	.74***	.88***	1***
	(.038)	(.036)	(.1)	(.099)	(.12)
$i_{CH} - i_j$	.069***	.075***	.029**	.051***	.038***
	(.0096)	(.0091)	(.011)	(.011)	(.014)
$\log(VIX)$	.16***	.097*	.099**	.095**	-.25**
	(.035)	(.05)	(.044)	(.043)	(.12)
$\log\left(\frac{\text{Real GDP}_{CH}}{\text{Real GDP}_j}\right)$				3***	2.3***
				(.29)	(.4)
Observations	612	612	612	612	612
R-squared	0.51	0.57	0.72	0.76	0.66
Kleibergen-Paap F-stat					24.5
Hansen J-stat p-val					0.06
Quad. trend	No	Yes	Yes	Yes	Yes
Country FE	No	No	Yes	Yes	Yes

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Note: The dependent variable is the convenience yield of Swiss government debt vis-à-vis country i's government debt, in basis points, at a 10-year maturity, $\eta_{t,10year,j}$. Government debts in ratio of government debt net of central bank holdings to GDP, multiplied by 100, so that the coefficients read as the effect of an increase in debt equivalent to 1 percent of GDP. The convenience yield is in basis points. The log of the ratio of real GDP indices is multiplied by 100, so that the coefficients read as the effect of a 1 percent increase in relative GDP.

Table 17: Drivers of the convenience yield - All maturities and horizons

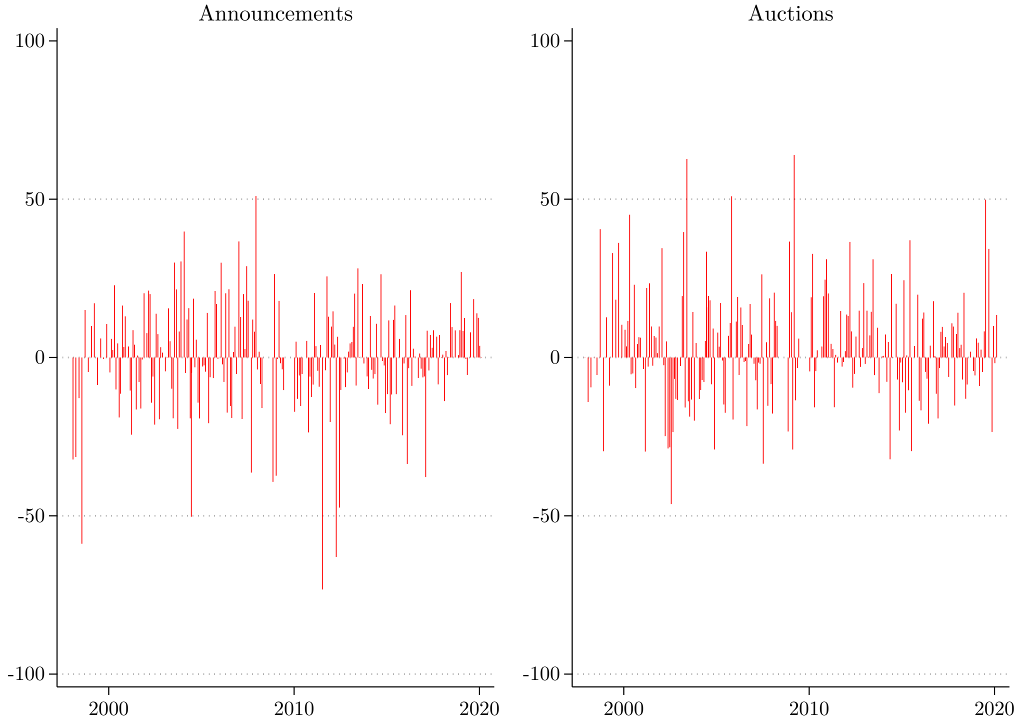
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	$\eta_{t,h,j}$	$\eta_{t+1,h,j}$	$\eta_{t+2,h,j}$	$\eta_{t+3,h,j}$	$\eta_{t+4,h,j}$	$\eta_{t+5,h,j}$	$\eta_{t+6,h,j}$
$h = 10y$	-32.90***	-29.76***	-30.34***	-22.49***	-31.55***	-25.43***	-25.62***
	(7.41)	(2.87)	(6.14)	(4.62)	(6.48)	(4.66)	(7.15)
$h = 7y$	-26.26***	-25.93***	-30.39***	-16.43***	-24.25***	-20.74***	-16.89***
	(7.61)	(3.01)	(5.78)	(4.77)	(6.12)	(5.35)	(6.32)
$h = 5y$	-23.95***	-23.38***	-25.76***	-6.55	-12.10**	-18.47***	-8.15
	(7.64)	(3.24)	(5.60)	(5.61)	(5.81)	(6.17)	(6.22)
$h = 3y$	-27.47***	-35.81***	-22.98***	-8.26*	-15.02***	-13.60**	-12.23**
	(6.90)	(3.91)	(4.70)	(4.90)	(5.57)	(6.22)	(6.08)
$h = 2y$	-25.84***	-29.66***	-18.79***	-6.91	-16.18***	-7.81	-15.58***
	(6.57)	(3.78)	(4.63)	(5.11)	(5.16)	(5.40)	(6.04)
$h = 1y$	-31.85***	-35.62***	-5.55	-6.91	-42.37***	-16.83***	-22.03***
	(7.30)	(4.42)	(5.34)	(5.06)	(9.69)	(5.48)	(7.65)
$h = 3m$	-31.19***	-20.31***	21.43***	0.46	1.61	15.71***	9.57
	(8.12)	(5.10)	(5.55)	(6.67)	(7.60)	(5.09)	(7.46)

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Note: The dependent variable is the convenience yield of Swiss government debt vis-à-vis country i's government debt in basis points, at maturity h, $\eta_{t,h,j}$. Government debt is the change in the ratio of government debt net of central bank holdings to GDP, in percentage points. Real GDP indices are equal to 100 in 2000. The log of real GDP indices are multiplied by 100, so that the coefficients read as the effect of a 1 percent increase in GDP. The countries in our sample are Australia, Canada, Denmark, Germany, Japan New Zealand, Norway, Sweden, Switzerland, United Kingdom, United States

Figure 23: Principal component of yield changes on announcement and auction days



Each plot of this figure shows the principal component underlying changes in Swiss government bond yields on announcement and auction days respectively. These are the daily series we cumulate over quarters to obtain the series of instruments that we use in our quarterly panel regressions. The left (right) panel plots the principal component precluding to announcements (auctions) days.

Table 18: The effect of central banks' sovereign debt purchases across maturities

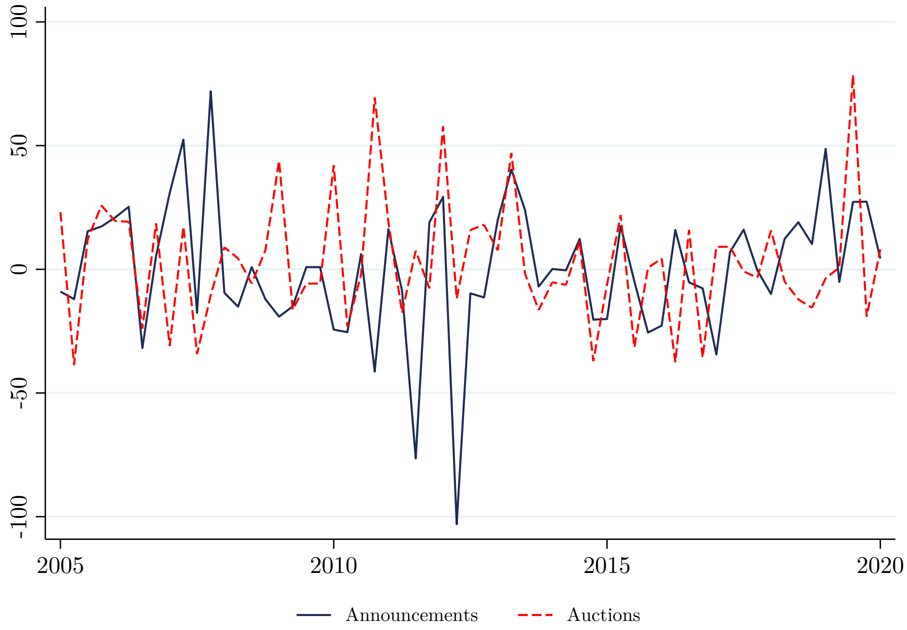
	(1)	(2)	(3)	(4)	(5)	(6)
	$h = 3m$	$h = 1y$	$h = 3y$	$h = 5y$	$h = 7y$	$h = 10y$
$\Delta \log(CB/GDP)_j$	-0.02	-0.03	-0.05**	-0.07***	-0.07***	-0.07***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
$\Delta \log\left(\frac{\text{ECB assets}}{GDP_{EA12}}\right) \#(j = EURO)$	-0.24	0.05	0.07	-0.23	-0.20	-0.58**
	(0.33)	(0.49)	(0.24)	(0.24)	(0.25)	(0.25)
Observations	630	628	628	630	628	602
R-squared	0.58	0.52	0.71	0.71	0.72	0.76
Quad. trend	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

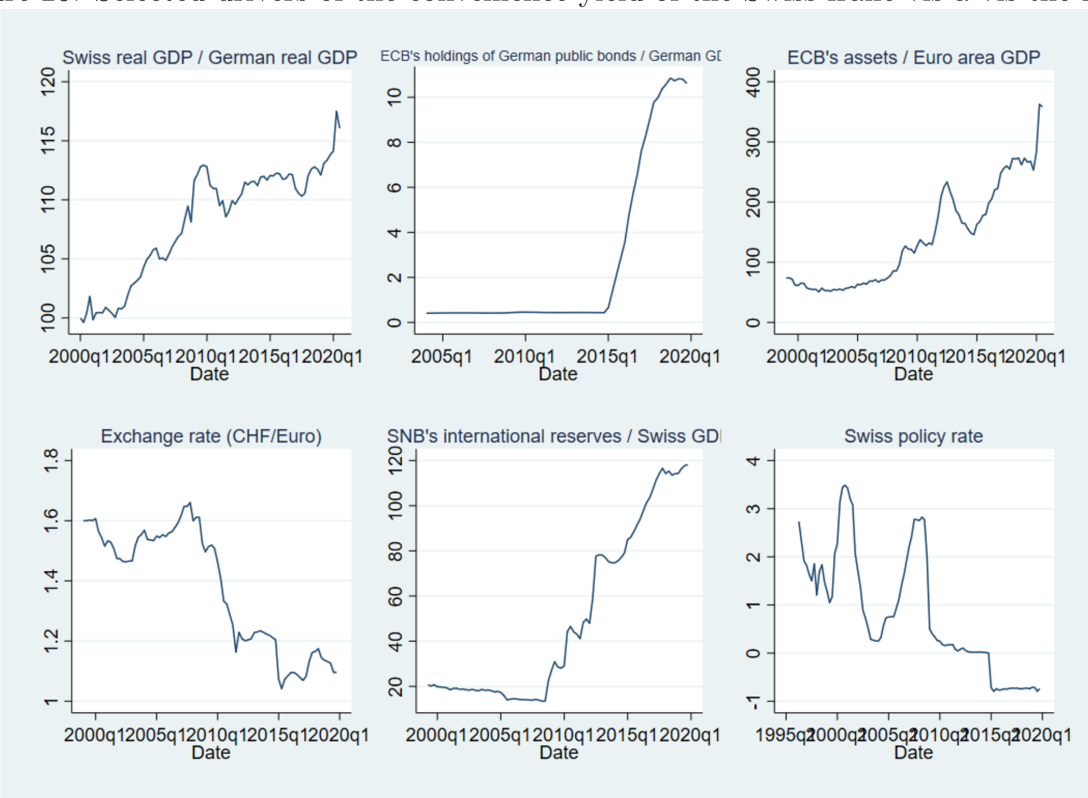
Note: The dependent variable is the convenience yield of Swiss government debt vis-à-vis country i's government debt, in basis points, at maturity h, i.e. $\eta_{t,h,j}$. Government debts are the quarterly changes in the ratio of gross government debt to GDP, in percentage points. The specifications of the regressions follow equation (13), only the dependent variables changes. We report only the coefficients of the Swiss public debt.

Figure 24: Quarterly instruments



This figure shows the cumulated principal component underlying changes in Swiss government bond yields on announcement and auction days respectively. These are the instruments we use in our quarterly panel regressions. The left (right) panel plots the instrument precluding to announcements (auctions).

Figure 25: Selected drivers of the convenience yield of the Swiss franc vis-à-vis the Euro



All the data is represented in percentage points.