Exchange Rates and Casualties During the First World War

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Abstract

I estimate a single factor model of Swiss exchange rates during World War I for five of the primary belligerents: Britain, France, Italy, Germany, and Austria-Hungary. At the outbreak of the war, these nations suspended convertibility of their currencies into gold with the promise that after the war each would restore convertibility at the old par. However, once convertibility was suspended, the value of each currency depended on the outcome of the war. A single factor extracted from these exchange rates contains information on contemporaries' expectations about the war's resolution. Innovations to the single factor are correlated with time series on soldiers killed, wounded, and taken prisoner.

1 Introduction

In 1903 Wesley Mitchell argued that many of the rapid and violent movements in the value of the Greenback during the U.S. Civil War could not be explained by changes in the volume of money outstanding as the quantity theory of money would predict; instead, many of these movements were the result of news from the battlefield. This is also the case for the currencies of five belligerent nations during World War I. In this paper, I estimate a single factor model of Swiss exchange rates from July 1914 to November 1918. The single latent factor extracted from these exchange rates is a measure of contemporaries' expectations of the war's outcome.

Throughout the First World War, Switzerland (a neutral country) traded with both sides of the conflict. Monthly data from Swiss foreign exchange markets indicate that while each of the belligerent governments tried to influence the value of their currencies during the war,

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they were not entirely successful. As the war progressed their ability to manipulate the Swiss currency markets declined, and the value of the belligerent's currencies relative to the Swiss franc fell throughout the war. While this relative decrease in currency values can be attributed to differences in money growth rates, it also appears that the value of the belligerents' currencies fluctuated with military news. In particular, good war news for the Allies increased the value of the Allied currencies relative to the currencies of the Central Powers and vice versa. To formalize these observations, I construct and estimate a single latent factor model. On the Allied side I have data on the British, French, and Italian rates. Of the Central Powers, I have data on German and Austrian-Hungarian exchange rates. Since I have data on both Central and Allied countries, I decompose movements in currency prices into movements due to a common factor and movements due to country-specific factors. The common factor rises with good news for the Allies and falls with good news for the Central Powers.

Using time series on casualties from the Western Front, I compute a "net body count" by subtracting the number of Germans killed and wounded from the number of British killed and wounded and a "net POWs" series by subtracting the number of Germans taken prisoner from the number of British taken prisoner. As noted elsewhere, despite losing the war, the net body count series was consistently in Germany's favor. Innovations to the common factor are positively correlated with the net body count series and negatively correlated with the net POWs series. Since offensive campaigns usually resulted in less favorable net body counts, these correlations suggest that being on the offensive was viewed positively by financial markets. The negative correlation between net POWs and innovations to the common factor suggests that the number of soldiers taken prisoner is a proxy for morale and the willingness of soldiers to continue fighting. Taken together, these findings support the view expressed by Niall Ferguson in his 1998 book *The Pity of War* that the key to victory in the First World War was not directly due to ones' ability to kill and wound the enemy, but rather due to the willingness of the enemy to surrender.

Traditionally during times of war, governments induced money- and bond-holding by promising, contingent on winning the war, postwar deflation. Bordo and Kydland (1995) argue that the gold standard, as practiced from 1880 to 1914, represented a state-contingent policy rule. During calm periods, each government on the gold standard kept the value of its currency fixed in terms of gold. But in the event of a well understood, exogenously produced crisis, such as a war, gold convertibility could be suspended with the understanding that, after the crisis had safety passed, convertibility would be restored at the old par. During the crisis, the government could issue paper money and sell debt to meet its short-term spending needs; but in doing so, it had to commit (either explicitly or implicitly) to eventually pay off this new debt in gold. Implicit in this policy rule is that after the resolution of the crisis, the government commits to undertake deflationary policies sufficient to return to the gold standard at the original parity.

Bordo and Kydland's (1995) view of the gold standard is consistent with theories of dynamic Ramsey taxation. In these models (see for example, Lucas and Stokey, 1983; Chari, Christiano, and Kehoe, 1994; and Sims, 2001), the optimal fiscal and monetary policy involves the government issuing and retiring debt with a state-contingent payoff that depends on the shocks to the present value of government surpluses. Through these state-contingent payoffs the government effectively purchases "insurance" from the public against fiscal shocks such as a war. The government smooths rates on distorting taxes by imposing capital losses on existing creditors in periods of high government spending (e.g., wartime). Likewise, when the government faces lower than average spending (e.g., at the outbreak of peace), the government reduces its level of debt and delivers capital gains to existing creditors.

This type of state-contingent policy was carried out by Britain in the Napoleonic Wars and to some extent by both sides in the American Civil War.[1] For the U.S., the Union was on a pure gold standard prior to the outbreak of the Civil War. During the hostilities the Union suspended specie payments and issued an unbacked currency, the greenback; this led to an increase in the money supply and a 70 percent rise in the price level during the war. Despite substantial political opposition, the U.S. undertook deflationary policies after the war that allowed it to return to convertibility at the pre-war parity in 1879. The Confederacy collected less than 10 percent of its total revenue from taxes during the war while currency generation accounted for nearly 60 percent of the Confederacy's revenue (Weidenmier, 1999). The Confederacy issued non-interest bearing notes (the graybacks) that specified a date that the government promised to redeem the obligations for gold. Not surprisingly, these Confederate notes were worthless at the conclusion of the war.

This use of nominal government obligations as a state-contingent fiscal shock absorber was

[1]See Bordo and White (1991) for a description of British debt management polices during the eighteenth and early nineteenth centuries. Bordo and White argue that Britain's fiscal and monetary policies were consistent with Barro's (1979) tax smoothing model with non-state contingent debt. I interpret changes in the price level as the mechanism Britain used to incorporate state-contingencies into its debt. See in particular figure 8.9 of Bordo and White.

carried out during the First World War. While Britain, Switzerland, and several Scandinavian countries (Denmark, Norway, and Sweden) all resumed convertibility at the original par by 1925, France and Italy chose to resume convertibility at new lower level of par. Germany (as well as the newly formed nations of Austria and Hungary) made no attempt to return to the gold standard immediately after the war but instead engineered a hyperinflation. Through this policy of hyperinflation the German government effectively defaulted on its nominal obligations and convinced the Allies to reduce the required reparation payments.

The issue of reparations is one potential contributing factor in leading the Allied and Central Power currencies to move in opposite directions. During World War I many contemporaries believed that much of the costs would be paid by the losers. Germany at the end of the Franco-Prussian War, in 1871, had imposed a large indemnity on France and hoped to do the same at the end of this war. Indeed throughout the war Germany made only modest attempts to finance its wartime expenditures through taxation and thus depended almost solely on loans to finance its military.[2] While the German government hoped to avoid the inefficiencies of additional direct distortionary taxation of its citizenry during the war, it believed it would be able to shift its costs onto Britain and France after the war. Dr. Karl Helfferich, Minister of Finance of the German government stated on March 10, 1915:

> The Federated Governments ... believe that they should not aggravate the already heavy burden of the war by new taxes or increases of taxes. ... We have a firm hope that after the conclusion of peace we shall present to our opponents a bill for the expenses of the war forced upon us. (Bogart, 1921 and Kuczynski, 1923)

On August 20, 1915 he went on to say:

> We do not wish to increase by taxation during the war the tremendous burden which our people bear, so long as there is no compelling necessity. ... As things are, the only method seems to be to leave the settlement of the war bill to the conclusion of peace, and the time after peace has been concluded. And on this I would say: If God grant us victory and with it the possibility of moulding the peace to suit our needs, we neither can nor will forget the question of costs. We owe that to the future of our people. The whole course of the future development of their lives must, if at all

[2] See Kuczynski (1923) for a detailed discussion of German tax policy during the war. Interestingly, Kuczynski argues that German fiscal policy was designed to cover expenses of the "peace budget, excluding army and navy" and the interest on war debt through taxation and to cover the expenses of the "peace budget for army and navy" and the wartime expenditures through debt. These intentions are consistent with the optimal tax smoothing policy implied by Barro (1979). The Germans were unsuccessful in carrying out this policy and much of the interest on the war debt was covered by new loans.

> possible, be freed from the appalling burden caused by the war. Those who provoked the war, and not we, deserve to drag through the centuries to come the leaden weight of these milliards.(Bogart, 1921 and Kuczynski, 1923)

This view was not uniquely held by the Central Powers.

Although the Allies used taxation to cover a larger share of their war expense than the Central Powers, there was little doubt during the last two years of the war that the Central Powers (particularly Germany) were expected to pay the bill for the damage caused by the war.[3] The Allies had repeatedly stated that their objectives in the war included "the restoration of Belgium, of Serbia, and of Montenegro, and the indemnities that are due them; the evacuation of the invaded territories of France, of Russia, and of Roumania with just reparation." (Burnett, 1965, Document 5, Reply of the Allies to Wilson, January 10, 1917.)

Even without the possibility of reparations, once off the gold standard each currency became a contingent claim that depended on the likelihood and timing of the country's return to the gold standard at the old par. These government obligations were both backward and forward looking objects. Restrictions imposed by the government budget constraint required the value of these obligations to depend not only on the quantity outstanding but also on the expected discounted present value of the future stream of primary surpluses. Hence as traders learned about the war's length and costs, forecasts of future government surpluses for the belligerents countries would generally move together; it follows that the value of all the belligerents' currencies should move together. However with the possibility of reparations, the expected value of future primary surpluses depended critically on the government winning or losing the war. Thus the government's ability to resume convertibility at the old par depended not only on when but also how the war would end. One would expect that the value of Allied currencies would at times move in opposite directions to those of the Central Powers. If this is the case, the value of these nominal government obligations provide information about contemporaries' expectations of the duration and resolution of the war.

The idea that war news influences the value of a nation's currency and other claims on the government is an old one. Mitchell (1903) recognized that currency prices were effected by news from the battlefield during the Civil War. Roll (1972) documents that during the Civil War federal

[3]Kuczynski (1923) reports that the tax revenue available to Great Britain for wartime expenditures was three times as high as in Germany.

bond prices and thus interest rates were also a function of war news. More recently Willard, Guinnane, and Rosen (1996) study daily price data for U.S. Greenbacks from the New York gold market. They employ a purely statistically method to distinguish between events that have a long-lived effects on prices ("turning points") and those events that simply generated "blips" in the data. Brown and Burdekin (2000) apply Willard, Guinnane, and Rosen's methodology to price data on Confederate bonds traded in Europe. These studies use data from one side of the war. But war is (at least) a two-sided activity, so it is useful to incorporate data from all sides. McCandless (1996) estimates a single-factor model for the U.S. Civil War using data on gold prices from both the Union and Confederacy. Weidenmier (1999) uses both Confederate and Union currency prices to test the hypotheses that the Union was fighting to win while the Confederacy was only fighting for a draw. Frey and Kucher (1997) use Willard, Guinnane, and Rosen's methodology to study the prices of German, Austrian, French, Belgian, and Swiss government bonds traded in Switzerland during World War II. Frey and Kucher analyze each of these countries individually. Ferguson (1998) argues that during World War I British bond prices in New York were a function of war news.

This paper is organized as followed. In the next section I discuss attempts by the various governments during the war to limit exchange rate movements. In the third section I describe the exchange rate data and do some preliminary analysis. In the fourth and fifth sections I formulate and estimate the model. In the sixth section I compare the single factor extracted from the model to casualty data from the Western Front.

2 Government Controls on Exchange Rates

Prior to the war, all five belligerent countries were either explicitly on the gold standard or had a policy of keeping the value of their currency near the nominal par.[4] By August of 1914, all five of these belligerent countries had effectively suspended convertibility of their currency into gold and placed restrictions on the exportation of gold. All of the belligerent nations made serious attempts to maintain stable exchange rates.

Although Great Britain did not de jure leave the gold standard until May 1917, it left the gold standard de facto in August 1914.[5] Between these two dates, paper currency was officially

[4]The material in this section is drawn from Young (1925).

[5]Exportation of gold was officially prohibited by proclamation on May 10, 1917.

redeemable for gold, but appeals to patriotism, bureaucratic barriers, and various new legal restrictions effectively stopped all gold redemptions. For example, in 1916 the melting down of gold coins became illegal. Throughout the war both the U.S. and British governments actively tried to maintain a stable sterling-dollar exchange rate. The United States made several large loans to Great Britain, and beginning in early 1916, the British government hired J.P. Morgan & Co. to conduct loan operations such that the sterling-dollar exchange rate was stabilized at $4.76. This "pegging" of the exchange rate, though quite expensive for the British government, was largely successful and continued until early 1919.

While the French were not technically on a pure gold standard before the war, they suspended species payments on August 5, 1914. In April, 1916 the French and British governments agreed to stabilize the franc-sterling exchange rate through gold exports from France to Britain and loans. During this time, the sterling-dollar exchange rate was also stabilized so the relative prices of US, French and British currency were effectively fixed for the remainder of the war. The United States government cooperated with both the French and the British governments to ensure that the relative exchange rates between these three nations never fluctuated substantially. The U.S. cooperation usually took the form of loans to Britain and France.

Italy, like France, was not officially on the gold standard prior to the outbreak of the war; nevertheless, the lira exchange rate with countries on the gold standard was never far from the nominal gold par. Italy entered the war in May 1915, but the value of the lira began to fluctuate at the outbreak of hostilities. In December 1917, the Italian government attempted to stabilize the value of the lira by forming the National Institute of Foreign Exchange. This institute was granted a monopoly in foreign exchange operations starting in March 1918. This attempt to stabilize the currency however proved to be ineffective. So in the summer of 1918, Italy made various agreements with the United States, Great Britain, and France to enter into the Allies fixed exchange rate agreement. Loans from the United States and Britain to Italy ensured the success of this arrangement.

While the Allies were eventually successful in their attempts to fix the intra-Allied exchange rates, the Central Powers had much less success. During the first week of war, Germany went off the gold standard and almost immediately engaged in a policy of using short-term (3-month bills) domestic credit to finance its war effort. While Germany was able from time to time to obtain some loans from Switzerland and the Scandinavian countries, it had substantial trouble obtaining long-term loans from foreign sources. As sources of credit started to run out, the German government tried several times to stabilize its exchange rates by regulatory means; most notably, on January 28, 1916 the Reichsbank and twenty-six banking firms in Berlin, Frankfurt and Hamburg formed a foreign exchange monopoly called the *Devisenzentrale.* This consortium fixed buying and selling rates on Austria-Hungary, the United States, Switzerland, and the Scandinavian countries. The Devisenzentrale carried out all foreign exchange and security transactions at these fixed rates. All incoming foreign exchange had to be turned over to the consortium, which became to sole seller of drafts on foreign countries. But even with such tight controls, this consortium was unable to maintain the value of the mark due to a lack of funds.

Like the other belligerents, Austria-Hungary suspended the central bank's obligation to buy gold at parity at the outbreak of the war. During the early years of the war Austria-Hungary began issuing large amounts of notes while simultaneously attempting to set controls on exchange rates. In February of 1916 a voluntary association of banks in Vienna was set up to control rates. By December 1916 this voluntary consortium was viewed as ineffective, so the government tightened foreign exchange controls. A *Devisenzentrale* was formed which all foreign exchange had to go through. In June 1918, the restrictions were tightened further such that all exports of goods and services had to be approved by the Devisenzentrale to ensure enforcement of the exchange rate restrictions.

Several features of the gold standard remained intact for the duration for the war. The definition of the gold content of the standard coins remained unchanged. The central banks and treasuries continued to honor their obligations to purchase gold at the fixed mint prices, and no restrictions were placed on the import of gold. Never the less, the existence of these consortiums and controls suggests that the war period was one of fixed prices. However, while some of these exchange rates were fixed successfully (e.g. the dollar-sterling-French franc), others were less successful. Maintaining fixed exchange rates is expensive. As the war progressed, the belligerents became poorer and their ability and willingness to maintain their exchange rates declined. All of these currencies fell in value relative to the primary neutral nations, Switzerland, Sweden, Denmark, and Spain.

3 The Exchange Rate Data

The exchange rate data are taken from Appendix VIII of the Swiss Bank Corporation report, *Revue Commerciale et Industrielle Suisse, 1914-1918* published in 1919. The data are monthly averages of the offer and demand quotations for sight drafts at the Basie bourse from July 1914 to November 1918.

I do not have data on the volume of trades that took place in Switzerland. However, there is evidence that foreign exchange was a relatively thick, liquid market in Switzerland during the war. The Swiss Bank Corporation (1919) states that during the war "In Switzerland, in Holland, and the Scandinavian countries, the operations in foreign exchange have taken on an unaccustomed, and surely temporary, importance." Both the Swiss Bank Corporation (1918) and the Federal Reserve Bulletin (1918) report that "Owing to its central geographic position, foreign exchange rates in Switzerland have come to be regarded as on the whole the most reliable basis for international comparisons."[6] Brown (1940, pages 13-14) reports that after the outbreak of the war "Remittance between the Central Powers and the Allied world continued to be made, though with difficulty, through markets of Germany's neutral neighbors. The Swiss foreign exchange market in particular became extremely important in the world economy for this reason ..."

Switzerland actively traded with both the Central and Allied countries. Table 1 shows that the Swiss traded roughly equal amounts with both sides throughout the war. While exports and imports fell at the outbreak of hostilities, as the war progressed trade with the belligerents increased. Multiplying each number in table 1 by 4.25 provides a rough estimate of the magnitude in 2001 U.S. dollars of Swiss trade with each of the belligerents.[7] So in 1915 Switzerland imported about $1.8 billion worth of goods (in 2001 dollars) from Germany and exported about $950 million worth of goods to France. Young (1925) also reports that Swiss private investors bought considerable amounts of foreign securities. This level of trade would support a sufficiently large volume of foreign exchange to ensure that the rate data I study are meaningful. Finally, I have exchange rate data for the five countries from three other neutral countries: Denmark, Sweden, and Spain. These exchange rates display qualitatively similar time series patterns to the Swiss rates. I use the Swiss rates because my Swiss dataset is the most complete of the four datasets

[6] The quote is taken from the Federal Reserve Bulletin (May 1, 1918, page 390) though it appears to have been translated directly from page 63 of the Swiss Bank Corporation (1918) *Revue Economique et Financiere Suisse.*

[7] During this time period, one Swiss franc was worth between 20 and 25 U.S. cents. One U.S. dollar in 1915 is equivalent to $17.50 in 2001.

country		1913	1914	1915	1916	1917	1918
Great Britain	*imports*	113	76	112	160	269	248
	exports	236	234	355	424	362	269
France	*imports*	348	221	189	236	305	208
	exports	141	115	220	401	462	466
Italy	*imports*	207	194	259	390	369	222
	exports	91	89	89	150	136	97
Austria-Hungary	*imports*	109	103	66	45	44	61
	exports	78	67	157	195	93	101
Germany	*imports*	631	481	418	472	483	619
	exports	306	274	457	709	698	445

Table 1: Swiss imports from and exports to each of the five belligerents, 1913-1918, in millions of nominal Swiss Francs.
Source: Swiss Bank Corporation, (1920) *La Situation Economique et Financiere de la Suisse: 1919*, page 36.

and the above quotes are convincing that the Swiss market was the primary exchange market during the war.

To check whether the exchange rates I study are a reasonable measure of the relative movements in the value of each of the currencies, I compare the exchange rate series to movements in these domestic price levels relative to movements in the Swiss price level. Of course, if purchasing power parity were to hold perfectly, the nominal exchanges rate for each country should equal the ratio of the Swiss price level to the domestic price level.

Unfortunately, it is impossible to obtain price indexes constructed using consistent methodologies across the various countries. I have a quarterly domestic price index for Switzerland and monthly domestic price indexes for Britain, France, Italy, and Germany.[8] In figures 1-4, I plot the value of the four currencies as measured by the exchange rate with Switzerland franc and as measured by the ratio of the Swiss price index to the belligerent country's price index. Each of these indexes are fixed weight (mostly equally-weighted) indexes; thus they do not handle rationing well and the substitution biases are probably quite large. Never the less the two measures

[8]For Switzerland, I use the price index constructed by the Union of Swiss Cooperative Societies and reported on page 6 of Swiss Bank Corporation (1919). For Britain the price index is the Statist index. It is an unweighted index of 60 commodities. It is taken from table 19 on page 454 of Young (1925). The French price index is the ensemble of 45 articles (commodities) taken from various issues of the *Bulletin de la Statistique General de la France*. The Federal Reserve Bulletin (January, 1920, page 28) states that this French index resembles the British Statist index in number and type of commodities. The Italian index is a wholesale price index of 40 commodities constructed by Professor Riccardo Bachi; it is taken from table 51 on page 507 of Young (1925). The German index, constructed by the *Statistiches Reichsamt*, is taken from table 63 on page 533 of Young (1925).

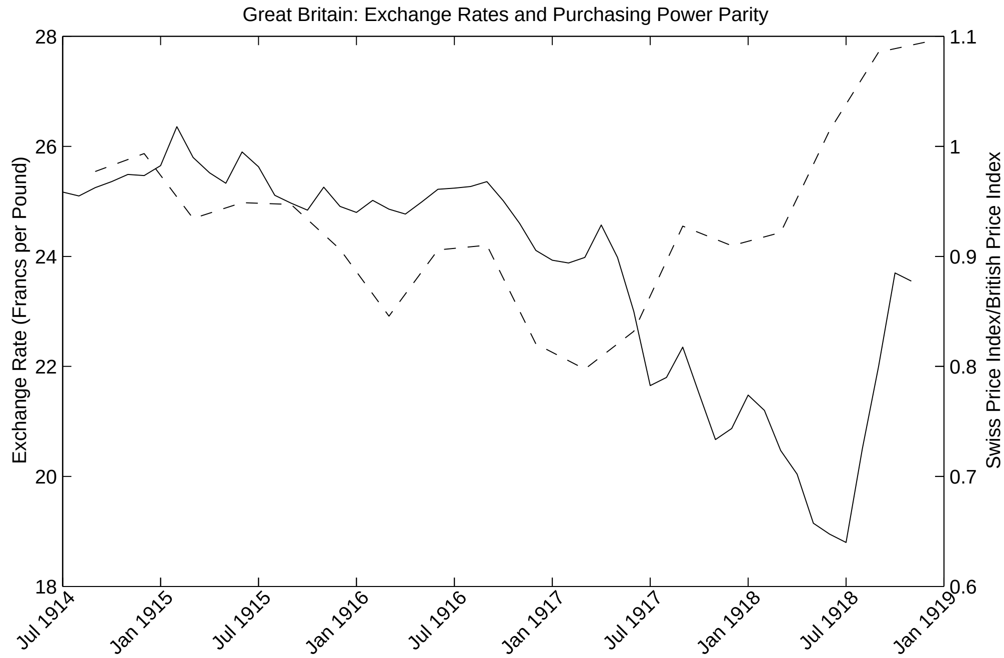

Figure 1: Britain: The exchange rate (solid line, left axis) and the ratio of domestic price indexes (dashed line, right axis).

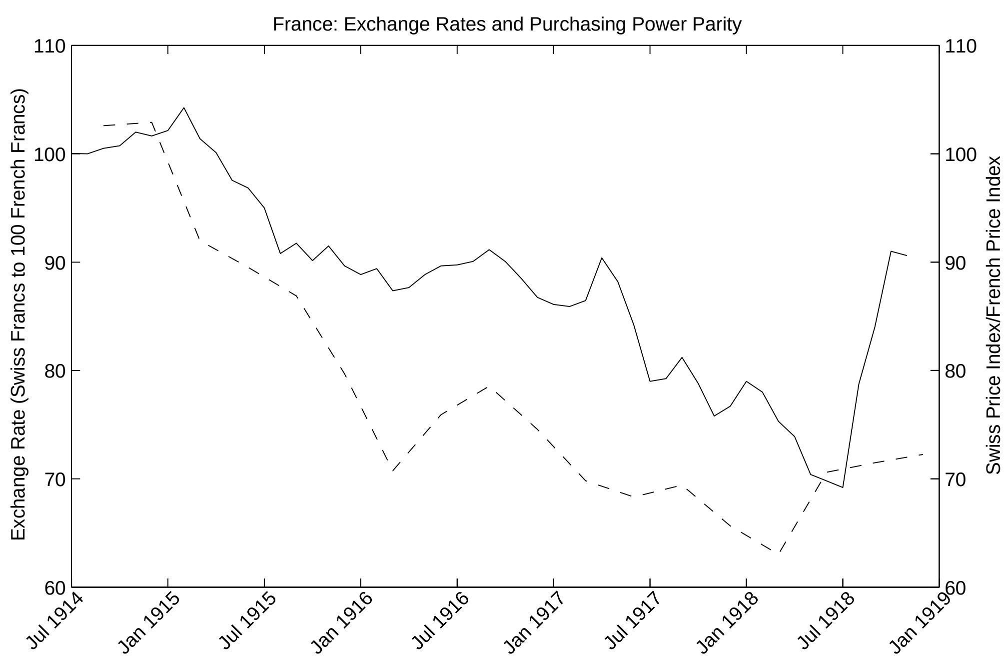

Figure 2: France: The exchange rate (solid line, left axis) and the ratio of domestic price indexes (dashed line, right axis).

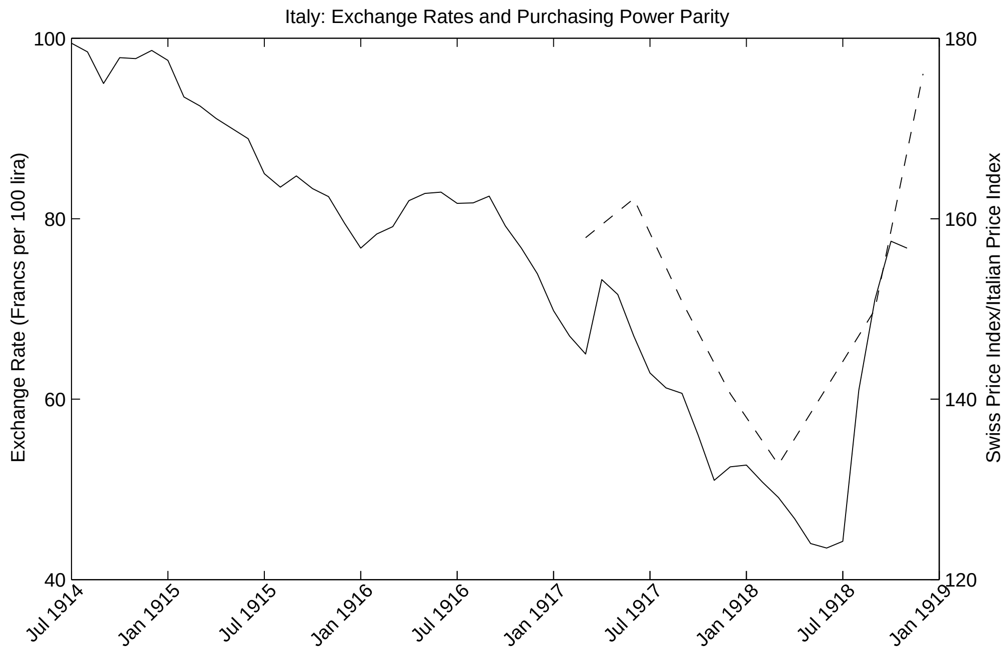

Figure 3: Italy: The exchange rate (solid line, left axis) and the ratio of domestic price indexes (dashed line, right axis).

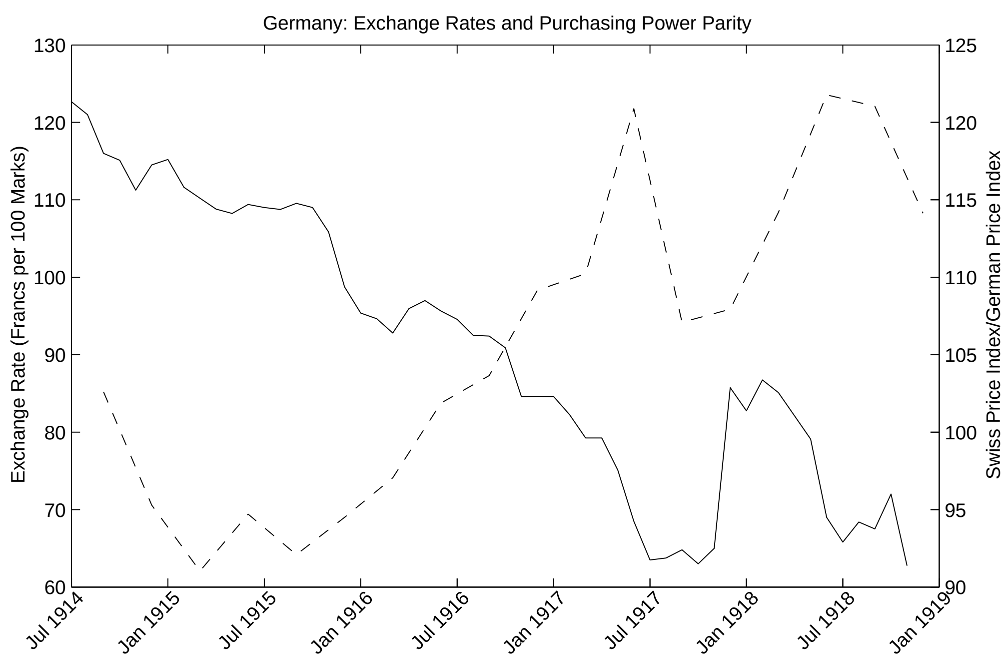

Figure 4: Germany: The exchange rate (solid line, left axis) and the ratio of domestic price indexes (dashed line, right axis).

seem to track each other reasonably well for three of the four countries. For Britain and France, each series bumps up in the summer of 1916 only to decline again in the fall, and each series turns up at the end of the war. Even for the short time period the two series overlap for Italy the basic shape of the two series is the same. Interestingly in the case of Germany, the two measures are almost inversely related.

Close inspection of figure 1 and 2 shows that after April 1916 the value of the British pound and the French franc move in lock step. Since the British pound-French franc exchange rate was effectively fixed during the second half of the sample, I perform the analysis below twice. The first time I use all five series, the second time I drop France. I refer to the former as the five-country analysis or model and the latter as the four-country analysis or model. I also repeated the exercise a third time keeping France in the sample and dropping Great Britain; these results are similar to four-country case so I do not report them.

To prepare the exchange rate data for analysis, I subtracted the mean from each series and divided each series by its own standard deviation. Hence $\frac{1}{T-1}Y'Y$ is the matrix of correlation coefficients of the standardized exchange rates where T is number of observations per series, and Y is a $T \times 5$ matrix of the standardized series. The series for Britain, France, Italy, Germany and Austria-Hungary are plotted in figure 5. Perhaps the most striking feature of this figure is the steady decline of all five currencies against the Swiss franc. The belligerents made repeated effort to maintain the value of their currencies; but even though the Swiss price level more than doubled during the war, they were unable to maintain the value of their currencies relative to the Swiss franc.

As a preliminary data analysis exercise, I computed the principal components of the five standardized exchange rates. Principal component analysis involves transforming the five standardized exchange rates into five score vectors. These vectors are pairwise-uncorrelated, linear combinations of the original data; the first series has the maximum possible variance under the constraint that the sum of squares of the coefficients is one, the second has the maximum possible variance among those uncorrelated with the first (again under the constraint that sum of squares of the coefficients is one), and so on.[9] For the five exchange rates, the first principal component, which is effectively two times the simple arithmetic average of the standardized series, accounts for nearly 88 percent of the total variance. It is the dashed line graphed in figure 6. The second

[9]For a discussion of principal component analysis, see chapter 11 of Anderson (1984).

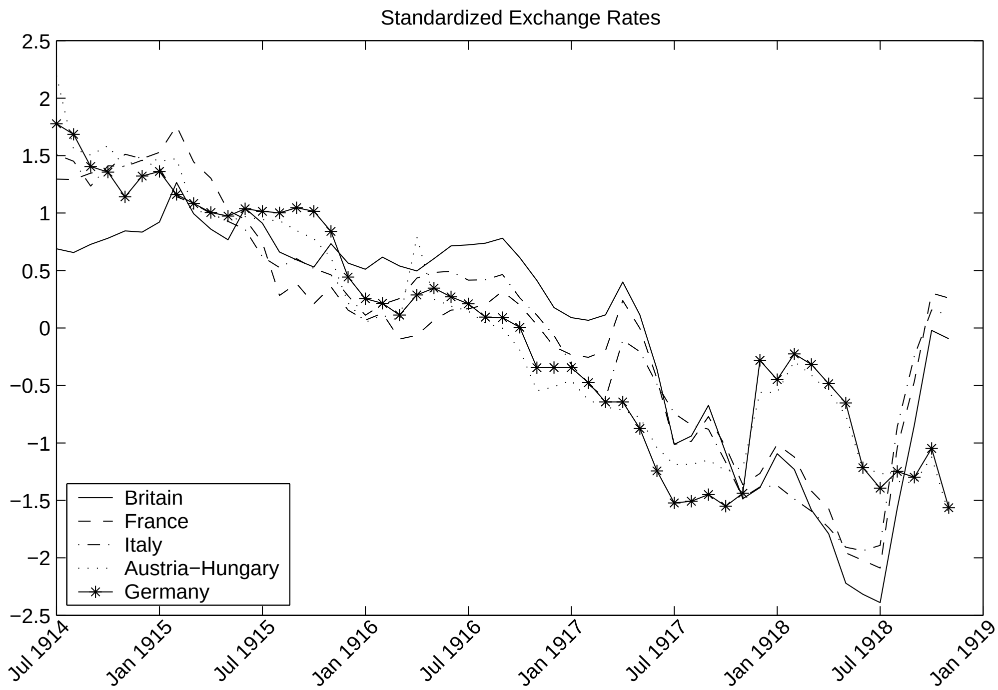

Figure 5: Exchange rates normalized to have a mean of zero and a standard deviation of one.

principal component, plotted in figure 8, accounts for over 9 percent of the total variance. Thus over 97 percent of the variation in the data is associated with just the first two components.

In every European country for which I have data there were large increases in both note circulation and other credits during the war. This of course led to sharp increases in prices throughout Europe. To determine how much of the relative movements in exchange rates are due to the relative increases in government obligations, I study the quantity of notes in circulation issued by the central banks for each of the five belligerents.[10] I divide each of these series by the total notes in circulation issued by the Swiss National Bank.[11] As with the exchange rate data, I normalize each series to have a mean of zero and a standard deviation of one. I then compute the principal components for these five series. The first principal component of these five series is the dotted line plotted in figure 6. It is highly correlated with the first principal component of the exchange rate series. The correlation coefficient is 0.92. This suggests that much of the decline in the value of belligerent currencies relative to the Swiss franc can be attributed to the relative

[10] These data are taken from Young (1925). While central bank notes in circulation is a very narrow measure of money, it is the only consistent monthly money series I could construct across all six countries.

[11] So, for example, the British series is Bank of England notes outstanding (in pounds) divided by Swiss National Bank notes outstanding (in francs).

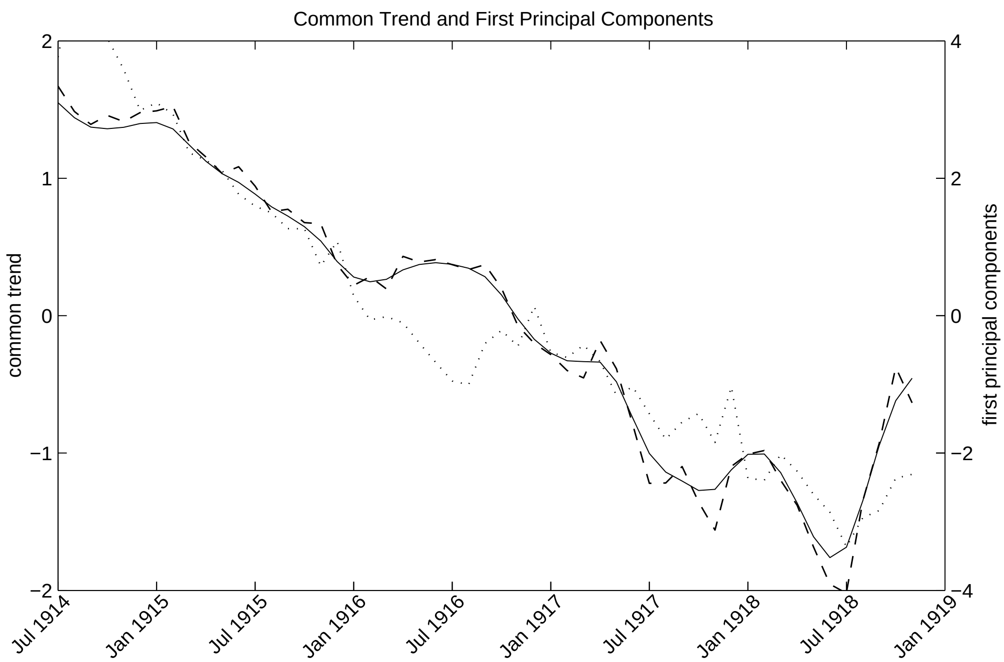

Figure 6: Common trend removed from each exchange rate series (solid line, left axis), first principal component of the exchange rates series (dashed line, right axis), and first principal component of the notes in circulation series (dotted line, right axis).

increases in the quantity of government obligations outstanding. The remaining four principal components from the notes series are less correlated with the remaining four principal components for the exchange rate series. The correlation coefficient between the second principal of the note series and the second principal component of the exchange rate series is 0.18; for the third, fourth, and fifth principal components the correlation coefficients are 0.07, -0.09, 0.05 respectively.

Due to purely mechanical approach of principal component analysis it is often difficult to attach concrete meaning to specific components. I want to interpret the second principal component of the normalized exchange rates as a measure of expectations about who is winning the war. Thus, I am going to extract these two "components" from the data in a less mechanical but more economicly meaningful way by explicitly detrending the data and estimating a single factor model. By using this second approach I will not only be able to construct components which I more comfortable attaching economic meaning to, I will also be able to construct measures of agents' best linear forecasts of future exchange rates. The difference between these forecasts and the actual data is a measure of new information about the war. Also by estimating a single

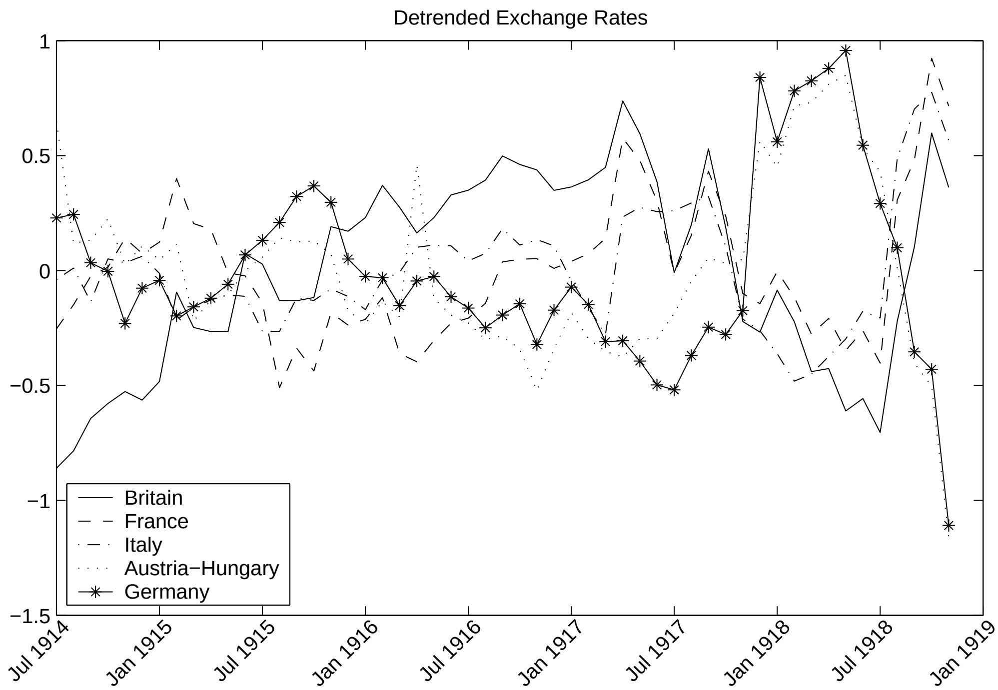

Figure 7: Detrended exchange rates

factor model, I can decompose exchange rate movements into a "common component" and a "country-specific component."

Guided by the observation that the first principal component behaves like an arithmetic average, I removed a common flexible trend from each of the exchange rate series. This effectively purges any Switzerland-specific effects from the data. Specifically, I summed the standardized time series and divided the aggregated series by its own standard deviation. I then Hodrick-Prescott filtered the aggregate series using a small value for the filter's Lagrange multiplier (i.e. $\lambda = 1$). The resulting trend, the solid line plotted in figure 6, is a slightly smoother series than either the arithmetic average of the standardized exchange rates or the first principal component. I then subtracted this common trend from each of the standardized series. These detrended series are displayed in figure 7. Throughout the war, but particularly after July 1915, the Allies rates and the Central rates tend move symmetrically. Also the size of the deviations from the common trend increases as the war progressed. The detrended exchange rates are used to estimate the factor model presented in the next section.

4 The Factor Model

The factor model consists of three equations.[12] The first equation is the transition equation for the single common factor. Let x_t denote the common factor at time t. I assume x_t follows the first-order auto-regression,

$$x_{t+1} = \rho x_t + w_{t+1}, \tag{1}$$

where $0 < \rho < 1$ and $\{w_t\}$ is a sequence of i.i.d. normal random variables with mean zero and variance one. I compute the latent variable, x_t, assuming that all the comovements of the exchange rates at all leads and lags arise solely from the movements in x_t.

The second equation is the observer equation. Let y_t denote the 4×1 vector of time t exchange rates: $y_t = [y_t^{\text{Britain}}, y_t^{\text{Italy}}, y_t^{\text{Germany}}, y_t^{\text{Austria}}]'$. Each element of y_t is a linear function of x_t plus a country-specific factor:

$$y_t = \mathcal{G} x_t + v_t \tag{2}$$

where $\mathcal{G}$ is a 4×1 vector of coefficients: $\mathcal{G} = [\gamma_{\text{Britain}}, \gamma_{\text{Italy}}, \gamma_{\text{Germany}}, \gamma_{\text{Austria}}]'$ and $\{v_t\}$ is the vector of country-specific factors. Thus each series is modeled to have a component attributable to the single common factor plus an idiosyncratic component. I allow the idiosyncratic component to be serially correlated:

$$v_t = D v_{t-1} + \eta_t, \tag{3}$$

where

$$D = \begin{bmatrix} d_{\text{Britain}} & 0 & 0 & 0 \\ 0 & d_{\text{Italy}} & 0 & 0 \\ 0 & 0 & d_{\text{Germany}} & 0 \\ 0 & 0 & 0 & d_{\text{Austria}} \end{bmatrix}$$

and η_t is a 4×1 vector of martingale differences sequences whose elements satisfy

$$\begin{aligned} E\eta_t^j \eta_s^{k\prime} &= \begin{cases} r_j & \text{if } t = s \text{ and } j = k \\ 0 & \text{otherwise} \end{cases} \\ E\eta_t w_s &= 0 \ \forall \ t \text{and } s \end{aligned}$$

for j and k equal to {Britain, Italy, Germany, Austria}. Let $\mathcal{R}$ denote a 4×4 diagonal matrix with the elements r^j along the diagonal. Finally θ denotes the $1 \times p$ vector of parameters to be estimated: $\theta = \{\rho, \gamma_{\text{Britain}}, \gamma_{\text{Italy}}, \gamma_{\text{Germany}}, \gamma_{\text{Austria}}, d_{\text{Britain}}, d_{\text{Italy}}, d_{\text{Germany}}, d_{\text{Austria}}, \sqrt{r_{\text{Britain}}}, \sqrt{r_{\text{Italy}}}, \sqrt{r_{\text{Germany}}}, \sqrt{r_{\text{Austria}}}\}$.

[12] To conserve space, I just present the four-country model.

This model differs slightly from the one employed by McCandless (1996). McCandless assumed that value of Union and Confederacy currency (y_t in my notation) obeyed the following process:

$$
\begin{aligned}
x_{t+1} &= \rho x_t + w_{t+1} \\
y_t - \mathcal{B} y_{t-1} &= \mathcal{G} x_t + v_t \\
v_t &= \eta_t
\end{aligned}
$$

where $\mathcal{B}$ is a diagonal matrix. McCandless estimates the diagonal elements of $\mathcal{B}$ to be between 0.9 and 1.0. Thus McCandless' model states the *change* in value of the currency is a linear function of the single factor. I assume the *level* of the value of the currency is a linear function of who is winning the war.

Parameter estimates are computed by maximizing the normal likelihood function with respect to the vector θ using the Kalman filter algorithm. This estimation procedure is discussed in more detail in Anderson, Hansen, McGrattan and Sargent (1996). The advantage of this estimation technique is that conditional on the parameter estimates, the Kalman filter produces a one-sided estimate of the latent factor. By extracting this latent factor, I compute a time series of 'who is winning the war'.

To derive the likelihood function, define $\bar{y} \equiv y_{t+1} - \mathcal{D} y_t$ and $\bar{\mathcal{G}} \equiv \mathcal{G}\rho - \mathcal{D}\mathcal{G}$ so equations (1), (2), and (3) can be rewritten as:

$$
\begin{aligned}
x_{t+1} &= \rho x_t + w_{t+1} && (4) \\
\bar{y}_t &= \bar{\mathcal{G}} x_t + \mathcal{G} w_{t+1} + \eta_{t+1}. && (5)
\end{aligned}
$$

Next, let $\hat{E}[Y|X]$ denote the linear least squares projection of Y onto X, and let $\mathcal{K}_t$ and Σ_t denote the time t 'Kalman gain' and 'state-covariance matrix,' respectively, of the time-varying Kalman filter. So, $\mathcal{K}_t$ and Σ_t satisfy: $\mathcal{K}_t = (\mathcal{G}' + \rho\Sigma_t\bar{\mathcal{G}}')(\bar{\mathcal{G}}\Sigma_t\bar{\mathcal{G}}' + \mathcal{R} + \mathcal{G}\mathcal{G}')^{-1}$ and $\Sigma_t = \rho^2\Sigma_{t-1} + 1 - (\mathcal{G}' + \rho\Sigma_{t-1}\bar{\mathcal{G}}')(\bar{\mathcal{G}}\Sigma_{t-1}\bar{\mathcal{G}}' + \mathcal{R} + \mathcal{G}\mathcal{G}')^{-1}(\bar{\mathcal{G}}\Sigma_{t-1}\rho + \mathcal{G})$. I then apply the Kalman filter to equations (4) and (5) to obtain the corresponding innovations representation:

$$
\begin{aligned}
\hat{x}_{t+1} &= \rho\hat{x}_t + \mathcal{K}_t u_t && (6) \\
\bar{y}_t &= \bar{\mathcal{G}}\hat{x}_t + u_t && (7)
\end{aligned}
$$

where $u_t = y_{t+1} - \hat{E}[y_{t+1}|y_t, ..., y_1, \hat{x}_1]$, $\hat{x}_t = \hat{E}[x_t|y_t, ..., y_1, \hat{x}_1]$ and $Eu_tu_t' \equiv \Omega_t = \bar{\mathcal{G}}\Sigma_t\bar{\mathcal{G}}' + \mathcal{R} + \mathcal{G}'\bar{\mathcal{G}}$.

The Gaussian log-likelihood function for $\{y_t\}_{t=1}^{T}$ conditioned on $\hat{x}_1$ is given by:

$$\log L(\theta) = -(T-1)\log 2\pi p - \frac{1}{2}\sum_{t=1}^{T-1}\log|\Omega_t| - \frac{1}{2}\sum_{t=1}^{T-1} u_t'\Omega_t^{-1}u_t \tag{8}$$

I initialize the system by setting $\hat{x}_1$ equal to zero (its unconditional mean), and Σ_1 equal to a large number (10 in this case). So implicitly v_1 is set to y_1.

5 Model Diagnostics

The point estimates and the standard errors of the parameters for both the five-country model and the four-country model are reported in table 2. For both models, the coefficients on the common factor for the Allies countries ($\gamma_{\text{Britain}}, \gamma_{\text{France}}$, and γ_{Italy}) are of opposite sign to the Central Powers (γ_{Germany} and γ_{Austria}). The common factor operates symmetrically on the two sides' currencies. Since the point estimates for the γ's for the Allies have a positive sign, increases in $\hat{x}_t$ can be interpreted as increasing chances that the Allies would win the war. Each of the point estimates of γ_i, with the exception of Austria-Hungary, are statistically different than zero at the 5% level. For the five-country model, the parameter estimates for Great Britain and France are quite similar. This is not surprising since the sterling-franc exchange rate was pegged from April 1916 to the end of the war. This fixed rate between the two currencies motivates my dropping France and estimating the four-series model.

In figures 8, 11, and 12 I plot the one-step ahead forecast of the common factor, $\hat{x}_t$ and the innovations to the common factor, $\mathcal{K}_t u_t$ series for the five-country model.[13] Interestingly, $\hat{x}_t$ is just a slightly smoother series than the second principal component. These two series, plotted in figure 8, are highly correlated with a correlation coefficient of .95. More importantly these series make intuitive sense. The $\hat{x}_t$ series reaches its global maximum during October 1918, the month prior to the signing of the Armistice. The second highest peak is April 1917, the month the U.S. declares war against Germany. It hits its nadir May 1918, during the middle of the Germans' last attempt to win the war. The largest negative innovation occur in November 1917 – the month the Bolsheviks under Lenin seized power in Russia and immediately opened peace negotiations with Germany. Four of the largest seven negative innovations are in late 1917 and early 1918. These were months in which there were plenty of good reasons for the Allies to be pessimistic: it

[13] The graphs of the corresponding series from the four-country model are qualitatively similar.

Parameter	Five-Country Model Point Estimate	Five-Country Model Standard Error	Four-Country Model Point Estimate	Four-Country Model Standard Error
ρ	0.83	0.15	0.95	0.10
γ_{Britain}	0.17	0.03	0.12	0.05
γ_{France}	0.18	0.04		
γ_{Italy}	0.10	0.02	0.08	0.03
γ_{Germany}	-0.19	0.06	-0.14	0.03
γ_{Austria}	-0.07	0.09	-0.13	0.05
d_{Britain}	0.91	0.08	0.70	0.12
d_{France}	0.96	0.06		
d_{Italy}	0.79	0.13	0.79	0.12
d_{Germany}	-0.03	0.26	-0.14	0.32
d_{Austria}	0.77	0.20	0.53	0.24
$\sqrt{r_{\text{Britain}}}$	0.075	0.015	0.168	0.021
$\sqrt{r_{\text{France}}}$	0.065	0.017		
$\sqrt{r_{\text{Italy}}}$	0.121	0.022	0.146	0.020
$\sqrt{r_{\text{Germany}}}$	0.188	0.032	0.097	0.024
$\sqrt{r_{\text{Austria}}}$	0.212	0.021	0.142	0.026
value of the log-likelihood	251.5		169.1	

Table 2: Estimation results

had become clear the Russians were pulling out of the war and thus the Germans would be able to concentrate more men and weapons on the Western Front; Italy had been routed in October 1917 at the Battle of Caporetto; and Serbia and Romania had been defeated. The $\hat{x}_t$ series and its innovations are discussed in more detail in the next section.

In table 3 and 4, the unconditional variance of the one-step-ahead forecast for each exchange rate is decomposed into the fraction due to the single common factor and the fraction due to the country-specific factor. From equation (2) we can derive

$$\text{var}(y) = \mathcal{G}\text{var}(x)\mathcal{G}' + \text{var}(v) \tag{9}$$

where $\text{var}(x) = \sum_{j=0}^{\infty}(\rho^j)^2$ and $\text{var}(v) = \sum_{j=0}^{\infty}\mathcal{D}^j\mathcal{R}\mathcal{D}^j$. In columns (1) - (3) of tables 3 and 4, I compare the total unconditional variance implied by the model to the variance of the detrended data. This is one measure of how well the model fits the data. Ideally these two numbers should be equal (i.e. the numbers in column (3) should be 1). The five-country model matches the second moments of the data for Italy and Germany. The model does less well for Britain, France

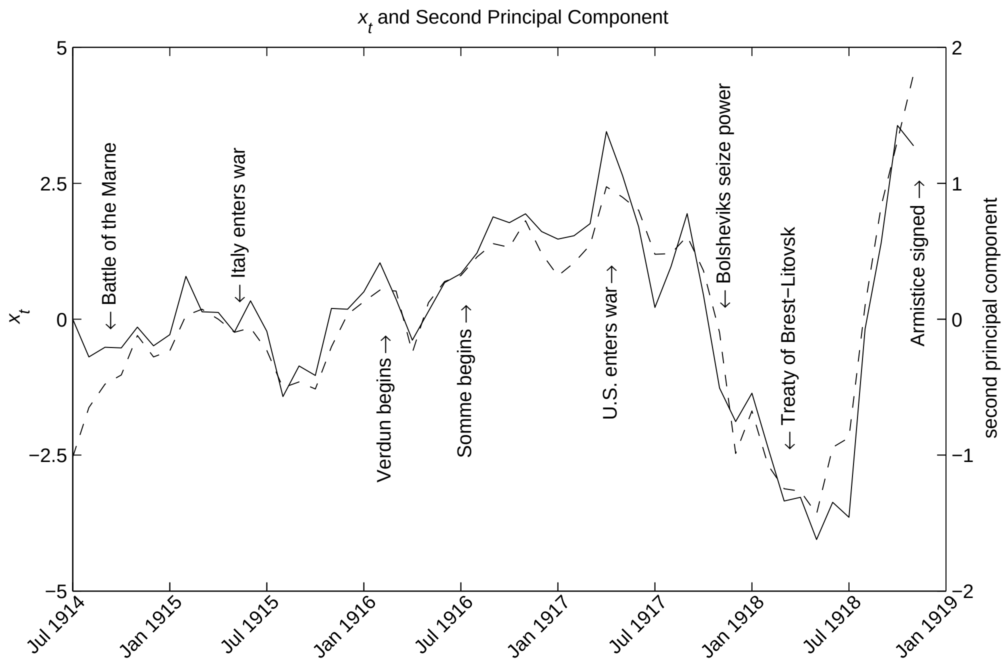

Figure 8: The one-step-ahead forecast of the common factor, $\hat{x}_t$, (solid line, left axis) and the second principal component (dashed line, right axis) for the five-country model.

series	variance data (1)	variance model (2)	Column (1)/ Column (2) (3)	common factor (4)	country-specific factor (5)	Column (4) / Column (2) (6)
Britain	0.172	0.132	1.31	0.099	0.033	0.75
France	0.091	0.167	0.55	0.106	0.061	0.63
Italy	0.071	0.069	1.03	0.030	0.038	0.44
Germany	0.146	0.148	0.98	0.113	0.035	0.76
Austria-Hungary	0.156	0.130	1.20	0.017	0.113	0.13

Table 3: Variance decomposition for the five-country model

series	variance data (1)	variance model (2)	Column (1)/ Column (2) (3)	common factor (4)	country-specific factor (5)	Column (4) / Column (2) (6)
Britain	0.194	0.189	1.03	0.134	0.055	0.71
Italy	0.100	0.125	0.80	0.067	0.057	0.54
Germany	0.115	0.192	0.60	0.182	0.010	0.95
Austria-Hungary	0.118	0.198	0.60	0.170	0.028	0.86

Table 4: Variance decomposition for the four-country model

and Austria-Hungary. The four-country model matches the unconditional variance of the British exchange rate but overestimates the variance for the other three countries. By this metric neither model fits the data well. However it is reassuring that both the common trend and $\hat{x}_t$ series are so similar to the first two principal components. By construction the five principal components exactly account for the variance of the normalized exchange rates. So if the second moments were the only moments I wanted to match (instead of the score of the likelihood function), I could use the score vectors from the principal components analysis. Doing so would generate all ones in column (3) of tables 3 and 4 but would not change the results in a meaningful way.

I also use equation (9) to decompose the variance implied by the model into the variance implied by the common factor (the fourth data column of table 3) and the variance implied by the country-specific factor (the fifth data column). For the five-country model, the common factor explains about 3/4 of the total variance for Britain and Germany, about 2/3 for France, 1/2 for Italy, and about 1/8 for Austria. For the four-country model, the common factor explains explains a larger fraction of the variances in each series. It accounts for 95 percent of the total variance of Germany and in contrast to the five-country case, it accounts for over 85% of the total model variance for Austria-Hungary. I can do a similar decomposition for the principal component analysis by computing the proportion of the variance of the normalized exchange rates (plotted in figure 5) left unexplained by the first principal component that is explained by the second principal component. For the four-country case, the second principal component explains 87 percent of the residual variance for Britain, 62 percent for Italy, 93 percent for Austria-Hungary, and 90 percent for Germany. For the five-country case, these numbers are 68 percent for Britain, 55 percent for France, 59 percent for Italy, 95 percent for Austria-Hungary, and 95 percent for Germany. A large fraction of the variance of each of these detrended series can be accounted for by a single factor. In other words, a large fraction of the movements in the detrended exchange rates arise solely from movements in $\hat{x}_t$.

The likelihood function was derived assuming the innovations, u_t, are white noise. As a quick check I regressed each innovations series ,$\{u_t^x\}$ where $x = \{$Britain, France, Italy, Germany, Austria$\}$, on a constant and one lag of the innovation. For all the series in both models the constant term was not significantly different than zero at the 5 percent level. But for two series (Italy and Germany) the coefficient on the lag innovation is significantly different from zero at the 5 percent level in both models.

6 Interpreting the $\hat{x}_t$ series

In this section I analyse whether movements in the $\hat{x}_t$ series, plotted in figure 8, and its innovations $\mathcal{K}_t u_t$, plotted in figures 11 and 12, correspond to well known historical events – in particular, events which would have led people to adjust their forecasts of the outcome of the war. However, just as the *Wall Street Journal* can "explain" every movement in yesterday's stock market, I can always find some event that explains every movement in the $\hat{x}_t$ series. Therefore I study whether the $\hat{x}_t$ series and its innovations $\mathcal{K}_t u_t$ are correlated with monthly data on casualties from the Western Front, food consumption in Germany and Great Britain, and British shipping losses.

During the first year of the war there is little movement in the $\hat{x}_t$ series – only minor oscillations around zero. During this period there is a modest upward trend in the second principal component. This discrepancy between the two series is partly due to how the Kalman filter is initialized. Recall I initialized $\hat{x}_1 = 0$. The second principal component is picking up the sharp appreciation of the British pound that is apparent in figures 5 and 7. After the outbreak of hostilities and the belligerents' decision to suspend convertibility, most of the belligerents' currencies rose slightly and traded above par as the belligerents attempted to quickly raise resources. This appreciation was more pronounced for the pound than for other currencies. It appears that the appreciation in the second principal component during this second half of 1914 is due more to the intense demand for funds in London than to battlefield news.

At the start of the war, most believed it would be short in duration and that both sides would be able to return to the gold standard quickly. But during the first few months of the war German armies made significant advances on the Western Front plowing through Belgium and seizing a large portion of northern France. The German army was only twenty-five miles from Paris in early September 1914 before being pushed back in the Battle of Marne. The Battle of the Marne ended any chance for a rapid Germany victory. The Western Front then stabilized as Allied and German troops tried to outflank each other culminating in the "The Race to Sea" in November. Neither these German advances nor Germany's inability to reach a quick decision in 1914 seem to have had much effect on the relative values of the five currencies.

During the first half of 1915, the common factor declined modestly (i.e. moves in the Central Power's favor). The Western Front was fairly stable during this time as both sides tried to "nibble" at each other's positions. During the spring the British also attacked the Dardanelles in Turkey.

Failure to obtain an Allied victory on either of these fronts caused the British government to change from Liberal to Conservative. According to Taylor (1980, page 86) this was the point at which it became clear to the British that the war would be costly and prolonged.[14] The German Army made significant advances on the Eastern Front against Russia. Between May and October of 1915, the German Army captured more Russian territory than the size of France. These British failures and the German advances on the Eastern Front appear to be reflected in the relative currency values.

Italy's entrance into the war on the Allied side in May of 1915 does not seem to have had much of positive effect on $\hat{x}_t$. Italy may have been perceived as much of a liability as an asset. The Italian Army was poorly equipped having not fully recovered from the Libyan War of 1912. Between their equipment problems and the line of mountains between Italy and Austria, the Italian were of little use in forcing Germany to send forces to the Southern Front. Furthermore, the British were already having to export coal to France since nearly all of the coal mines in north-eastern France were behind enemy lines; now the British were having to supply the Italians as well.

The $\hat{x}_t$ series suggests that currency traders felt the tide of the war shifted toward the Allies in late 1915 and throughout 1916. In late September and early October 1915 the French attempted an ill-fated offensive on German lines in Champagne. The attack was repelled. Despite outnumbering the Germans by more than three-to-one, the French suffered over three times the number of casualties. After this failure, $\hat{x}_t$ actually appreciates. The two major engagements on the Western Front during 1916 are the German attack on the French fort at Verdun and the British offensive at the Somme. On the Eastern Front, the Russians made substantial gains during the first half of the year before having these gains reversed by Germany in the fall.

The German attack on Verdun from February to June 1916 was an attempt to deal France a psychological blow as well as to force France to incur great losses in men and equipment. While German armies did succeed in inflicting a large number of casualties on the French (over 500,000 men), German losses were also huge (over 400,000 men) and the fort remained in French hands. The British attack at the Somme generated shockingly long causality lists but little gains in terms of territory for either side. As is well known, on the first day of the Battle of Somme, July 1, 1916,

[14]But it is interesting to note in figure 6 that all five currencies began a long steady decline relative to the Swiss franc months earlier.

the attacking British army suffered casualties which exceeded 60,000 men (of which about 20,000 were fatalities) while German casualties were only about 8,000. Verdun and the Somme had a large effect on the morale of all three armies. The heavy German casualties contributed to the Kaiser's decision to replace Falkenhayn with Hindenburg as Chief of the General Staff. Dupuy and Hammerman (1967) state these two battles also brought home to Germany the possibility of defeat. While some argue that German morale never fully recovered from the combined impact of theses two battles, British and French morale also suffered forcing the French General Joffre to resign. While the $\hat{x}_t$ series fell in early 1916 with large negative innovation in February and March (coinciding with the start of the Battle of Verdun), somewhat surprisingly the $\hat{x}_t$ series remained positive and continued to rise during the middle of 1916 despite the large British losses at the Somme.

There is large spike in the value of Austrian-Hungarian currency in March of 1916. See figure 7. I have not seen any discussion of this spike in any of the financial accounts. There was no significant battle news involving the Austrian-Hungarian army that month, but in the previous month the Austrian-Hungarian government had set up a consortium of banks to regulate rates. This spike is probably due to the effect of the consortium rather than battle news.

The $\hat{x}_t$ series peaks in April of 1917, the month the U.S. declared war of Germany, and one month after the Russian revolution. In mid-March of 1917 the Russian Revolution began and within days the Czar was forced to abdicate his throne. Taylor (1980) states that the Russian Revolution was "hailed with great rejoicing" by the West. According to Taylor, the West thought that the revolution would only make the Russian Army stronger. The third largest positive innovation occurs in March of 1917. See figures 11 and 12. With monthly data I cannot disentangle whether this large innovation was due to the Russian Revolution or anticipation of the American entrance into the war; never the less the timing makes sense.

In the last two years of the war, the detrended exchange rates move more dramatically. After April 1917 both the $\hat{x}_t$ series and the second principal component drop sharply, and decline steadily throughout 1917 as a series of bad news hit the Allies. A large mutiny in the French army from May to August limited French military capabilities. In October and November of 1917, the Italian Army suffered one of its largest defeats in the Battle of Caporetto. The outcome of this battle led to a substantial depreciation of the lira. This shows up in the large negative innovations for the Italian exchange rate u_t^{Italy} from September 1917 to January 1918. Military successes and the utilization of credits from the U.S. and Britain in the summer and fall of 1918 led to increases in the lira's relative value.

As mentioned above, large negative innovations occur in late 1917 in particular in the months of September, October, and November. In November of 1917 the Bolsheviks seized power in Petrograd and the Congress of Soviets called for peace. Ferguson (1998, pages 333-336) reports that prices in New York for the *1915 Anglo-French 5 per cent* coupon bonds fell dramatically in late 1917, hitting a nadir in December. Prices for these bonds recovered steadily throughout 1918. Ferguson states "The surprising thing is that the New York market remained so bullish about the Anglo-French bonds the following spring when many influential figures in Britain and France sincerely feared Germany was on the brink of victory." Using Swiss exchange rates, the story is a little different. While the $\hat{x}_t$ series drops to -1.9 in December it rebounds slightly to -1.4 in January 1918 before steadily declining to a nadir of -4.1 in May 1918. So the movements in the Swiss foreign exchange market in early 1918 are less surprising and more consistent with the perceived mood of "many influential figures in Britain and France" than the New York bond market; however these declines in the $\hat{x}_t$ series make the rise in bond prices all the more puzzling.

Furthermore, all the belligerent currencies rose in value at the end of 1917 and start of 1918. See figures 5 and 6. Not only were the Bolsheviks calling for peace at this time, but President Woodrow Wilson outlined his fourteen points in January of 1918 and called for a peace without reparations in February of 1918. This parallel increase in currency values is consistent with the idea that these calls led currency traders to decrease their expectations about the war's duration. However these peace proposals were rejected by Britain, France and Germany. Furthermore the collapse of Russia and these calls for peace appear to have led Germany to harden its negotiation position thus increasing the length of the war. This uniform increase in currency values was short lived.

The collapse of Russia also permitted the transfer of German troops to the Western Front giving the Germans numerical superiority, but it also hardened Germany's negotiating position. The Germans planned a final effort to win in France before the United States could intervene. At the end of March 1918 the Germans began a final offensive. The Germans were able to split the French and British line and by June were only fifty-six miles from Paris. Even though the German advance was not stopped until July, the $\hat{x}_t$ series turns in May. After the war Ludendorff, the commanding general of the Germany Army, referred to August 8, 1918 as "the black day of German Army." Ludendorff felt that a relatively minor Allied victory on this date finally shattered the German Army's faith in any potential victory. The $\hat{x}_t$ series suggests that the currency markets foresaw this "black day" months earlier.

While this informal review suggests military events are important in describing the movements of exchange rates, I recognize that I can always find some event that explains every movement in each of the five exchange rates. Therefore I restrict myself by comparing the $\hat{x}_t$ series to military data on the progress of the war. The best battlefield data I could find are casualty data.

The data I have on British and German casualties are taken from the War Office (1922).[15] I obtained data on French casualties from Larcher (1934).[16] I was unable to get times series data on American casualties. I focus on the Western Front for two reasons. First, I was unable to get any reliable military data on either the Southern or Eastern Fronts. Second, most historians I have read argue that winning on the Western Front was the key to winning the war.[17] Indeed the Germans won the Eastern Front defeating Russia, Romania and Serbia but lost the war.

Reported casualty statistics are notoriously noisy and at best a rough approximation of the number of military personnel killed, wounded and taken prisoner each month during the war. While casualty data are a crude way to measure military effectiveness, it is not obvious a better metric exists. Offensive capabilities were so inferior to defensive strategies and tactics that neither side could advance fast enough to make a breakthrough. From November 1914 to March 1918 the Western Front was a continuous line of trenches from Switzerland to the North Sea which remained virtually unchanged. Any territorial gains made on either side were negligible and often the result of the other side falling back to positions on better protected ground. Since neither side had much success in capturing territory, both sides implemented a strategy of attrition hoping to wear down or use up the other sides' stock of men. Ferguson (1998, chapter 10) cites several military leaders expressing the view that the Allied strategy was "to kill as many Germans as possible with the least loss to ourselves." The German Chief of the General Staff Falkenhayn argued for attacking the French fort at Verdun in order "to bleed France white." So data on soldiers incapacitated do

[15]The British data are for the British Expeditionary Force (BEF) in France and include the Regular Army and Territorial Force as well as the armies of Canada, Australia, New Zealand, Newfoundland, South Africa, and India. The German data are originally from the Federal Archives Office at Potsdam. Neither series includes deaths from wounds or disease since these data are not available for the German army. None of the results are sensitive to including deaths from wounds or disease for the BEF.

[16]The French data are from the French Health Service. They are aggregate casualty data, so they include killed, wounded, died from wounds, died from disease and taken prisoner.

[17]See for example Ferguson, 1998, pages 290-292 and the citations contained within.

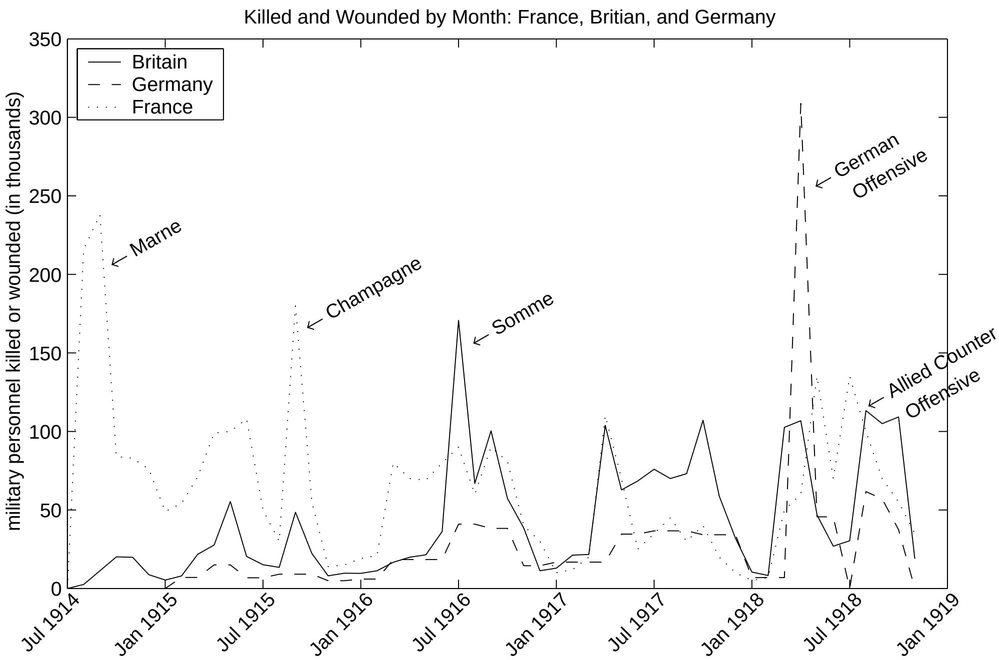

Figure 9: British and German soldiers killed and wounded and French total casualties by month.

provide a metric which contemporaries themselves used to measure combat effectiveness.

As noted by others (i.e. Dupuy, 1977 and Ferguson, 1998), if combat effectiveness is measured by the numbers of men killed and wounded, the Allies failed miserably. In figures 9 I plot the number of killed and wounded. There are three striking features of the data. The first is the magnitudes on the numbers of killed and wounded each month; in an average month on the Western Front 45,000 British troops and 27,000 German troops were killed and wounded. The French armies absorbed on average 63,000 total casualties per month. These are enormous numbers. Second is the persistent imbalance in German and Allied casualties. Despite losing the war, the Central Powers were far better at inflicting casualties on their enemy than were the Allies. According to the data I have, German soldiers on average killed or wounded over three British soldiers for every two German soldier killed or wounded. Moreover this ratio does not include French and Americans killed and wounded.[18] Only in the Spring of 1918 when the

[18] I think this is an overstatement of German military superiority. Dupuy (1977) reports that the German army inflicted on the total Allied force around three casualties for every two that were inflicted on them. I cannot determine the differences between the data I have and the data others report.

As another illustration of the contradictory nature of casualty data, Gilbert (1994, p 299) states that the death toll at the Somme for the months July-October 1916 was 95,675 for the British, 50,729 for the French, and 164,055 for the Germans. He reports that on November 1, the Allies announced that in the preceding four months, they had taken 72,901 German prisoners and captured 303 artillery pieces, 215 mortars and nearly 1,000 machine guns.

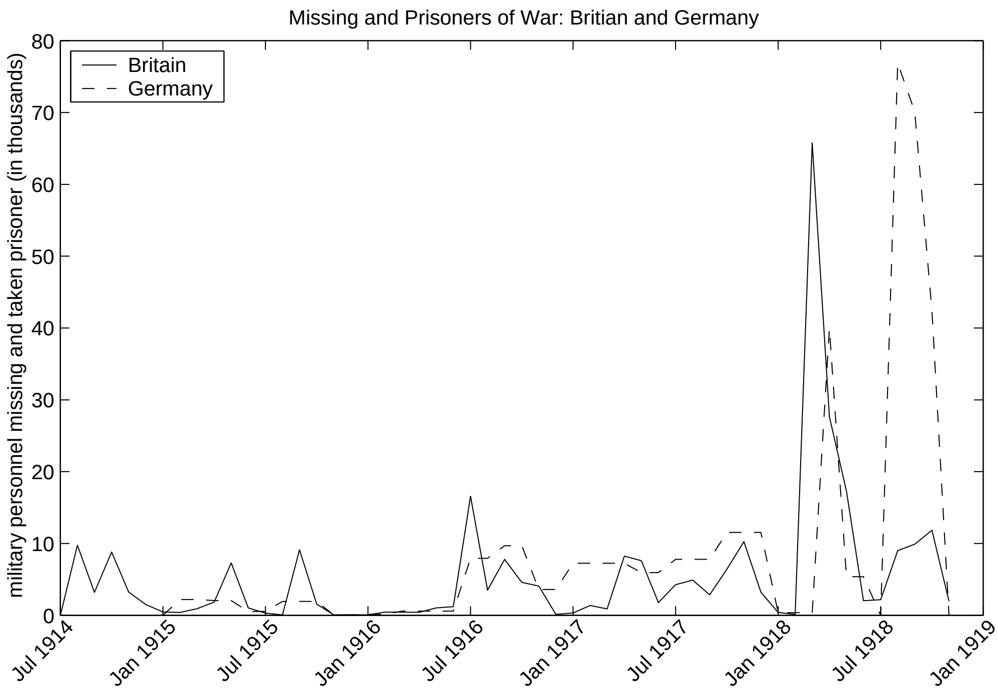

Figure 10: British and German soldiers missing and taken prisoner by month.

Germans launched their final offensive did they suffer higher casualties than the Allies. Third is the seasonal pattern to the casualty data. Most major battles occurred in the spring and summer months while the winter months were periods of relative calm. I do not see a seasonal pattern in the exchange rate data so any attempt to link casualty data to exchange rate data will not succeed entirely.

I do not know how quickly market participants learned of events from the battlefield. For example, Dupuy and Hammerman (1967) reports that after the French Offensive in Champagne in early October 1915, the Allies publicized their capture of 25,00 prisoners and 150 guns, but kept their casualties – 30,000 killed and missing, 100,000 wounded – a carefully guarded secret to avoid damaging civilian and military morale. Since I am using monthly averages, it is not important whether market participants took hours or days to react to news from the front, but given the work by Willard, Guinnane, and Rosen (1996) using daily price data from the Civil War, I expect news from the battlefield traveled quickly.

He does not cite his source. In contrast to the data I use, these data suggest that more Germans were killed than Allies during the Battle of the Somme. Note that the British and French did not (or Gilbert failed to) report the number of Allied troops taken prisoner.

	French total cas	British K&W	German K&W	Net Body Count	British taken POW	German taken POW	Net POWs
$\hat{x}$	-0.19	0.17	-0.23	0.36	-0.33	0.09	-0.28
$\mathcal{K}_t u_t$	0.14	0.06	-0.16	0.20	-0.09	0.29	-0.33
$u^{Britain}$	0.11	-0.01	-0.18	0.17	-0.10	0.23	-0.28
u^{France}	0.09	0.01	-0.13	0.16	-0.05	0.22	-0.24
u^{Italy}	0.24	0.11	0.04	0.06	0.02	0.26	-0.22
$u^{Austria}$	-0.16	-0.10	0.15	-0.22	0.14	-0.36	0.39
$u^{Germany}$	-0.18	-0.13	0.07	-0.22	0.11	-0.32	0.38

Table 5: Correlation Coefficients between Casualty Data and Series Imputed from the Five-Country Factor Model
Net body count is the number of British killed and wounded minus the number of Germans killed and wounded. Net POWs is the number of British taken POW minus the number of Germans taken POW.

In World War I defensive capabilities were considerably better than offensive tactics and weapons. A handful of well positioned machine guns and a line of barbed wire could hold up a much larger attacking force until reinforcements could be brought in. Thus high casualties were often associated with offensive campaigns. Following Ferguson (1998) I compute a "net body count" by subtracting the number of Germans killed and wounded from the number of British killed and wounded. In tables 5 and 6 I report the correlation coefficients between the casualty data and various series imputed from the five-country and four-country factor models. The data on soldiers killed and wounded are modestly correlated with the $\hat{x}_t$ series and its innovations $\mathcal{K}_t u_t$. For the five-country model, the correlation coefficient between the net body count and $\hat{x}_t$ is 0.36; the correlation coefficient between the net body count and $\mathcal{K}_t u_t$ is 0.20. These coefficients for the four-country model are 0.36 and 0.14. Thus an increase in Allied casualties relative to German casualties is associated with positive innovations to $\hat{x}_t$ and higher values of $\hat{x}_t$. Across both models, Allied troops killed and wounded are associated with positive u_t's for Britain and France and negative u_t's for Germany and Austria-Hungary. The reverse also holds true: German killed and wounded data are positively correlated with German and Austrian innovations and negatively correlated with British and French innovations.[19] So a higher net body count is associated with good news for the Allies.

This positive relationship between high Allied casualties relative to German casualties and positive innovations to the common factor suggests that being on the offensive was viewed positively

[19]Recall the likelihood function is derived assuming the u_t's are white noise. For both models, the u_t's are correlated across countries. Clearly not all the comovements of the exchange rates arise solely from changes in x_t.

	French total cas	British K&W	German K&W	Net Body Count	British taken POW	German taken POW	Net POWs
$\hat{x}$	-0.16	0.11	-0.29	0.36	-0.37	0.02	-0.25
$\mathcal{K}_t u_t$	0.20	0.13	-0.05	0.14	-0.02	0.35	-0.35
$u^{Britain}$	0.04	0.10	-0.12	0.16	0.06	0.31	-0.32
u^{Italy}	0.27	0.13	0.08	0.05	0.05	0.34	-0.27
$u^{Austria}$	-0.23	-0.09	0.03	-0.10	0.05	-0.26	0.29
$u^{Germany}$	-0.14	-0.12	0.05	-0.16	0.01	-0.28	0.28

Table 6: Correlation Coefficients between Casualty Data and Series Imputed from the Four-Country Factor Model
Net body count is the number of British killed and wounded minus the number of Germans killed and wounded.
Net POWs is the number of British taken POW minus the number of Germans taken POW.

by financial markets. As mentioned above, offensive campaigns tended to result in unfavorable net body counts. As one can see in figure 11, several of the largest positive innovations occur around Allied offensives (e.g. the 1918 counter offensive), and several of the largest negative innovations occur around German offensives (e.g. Verdun and 1918 final offensive).

While a higher net body count is associated with positive contemporaneous innovations, the reverse holds true for prisoners of war. As the last three columns of tables 5 and 6 show, the casualty series most correlated with the series imputed from the factor models is German soldiers taken prisoner. For the five-country model, the correlation coefficient between number of German's taken prisoner and innovations is 0.35. The correlation coefficient for net POWs (British taken prisoner minus Germans taken prisoner) the correlation coefficient is -0.35. The correlation between between innovations and lagged net POWs is even greater: -0.57 These results are consistent with Ferguson's (1998) thesis that the key to victory in the First World War was not directly due to ones ability to kill the enemy, but rather due to the willingness of soldiers on the other side to surrender. To quote from chapter 13 of Ferguson (1998):

> Surrendering was the key to the outcome of the First World War. Despite the huge death rolls, it proved impossible to achieve the ideal objective of pre-war German doctrine, 'annihilation of the enemy': demographics meant that there were more or less enough conscripts each year to plug the gaps created by attrition. For that reason the 'net body count' in the Central Powers' favour was not enough to bring them to victory. However it did prove possible to get the enemy to surrender in such large numbers that his ability to fight was fatally weakened.
>
> People at the time knew that large captures of enemy troops were a good sign. Around 10 percent of the British film *The Battle of the Somme* is devoted to pictures

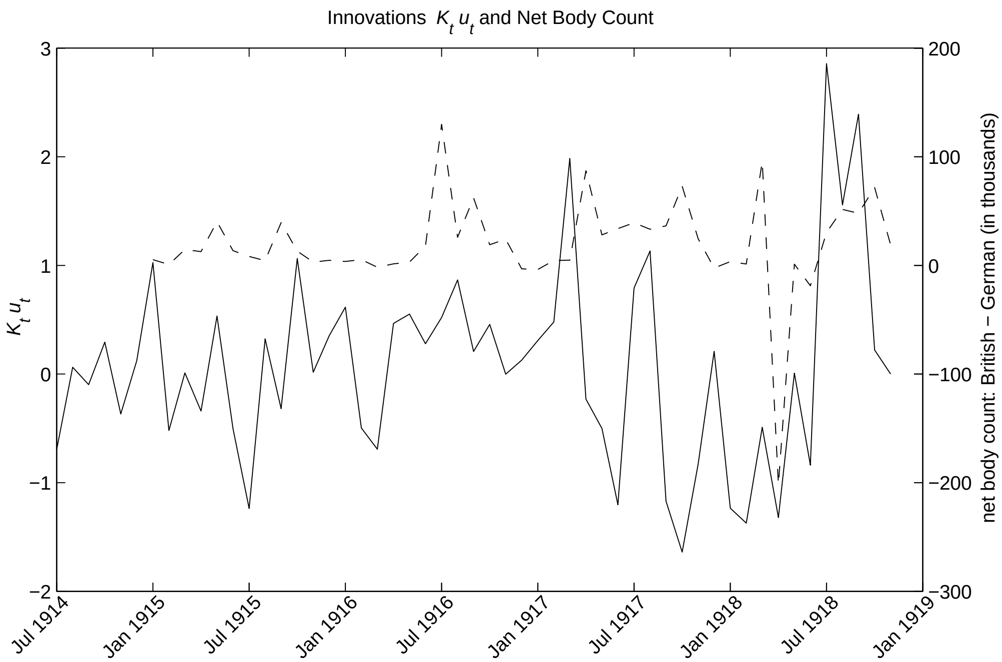

Figure 11: Innovations to the common factor, $K_t u_t$, (solid line, left axis) and the net body count (dashed line, right axis).

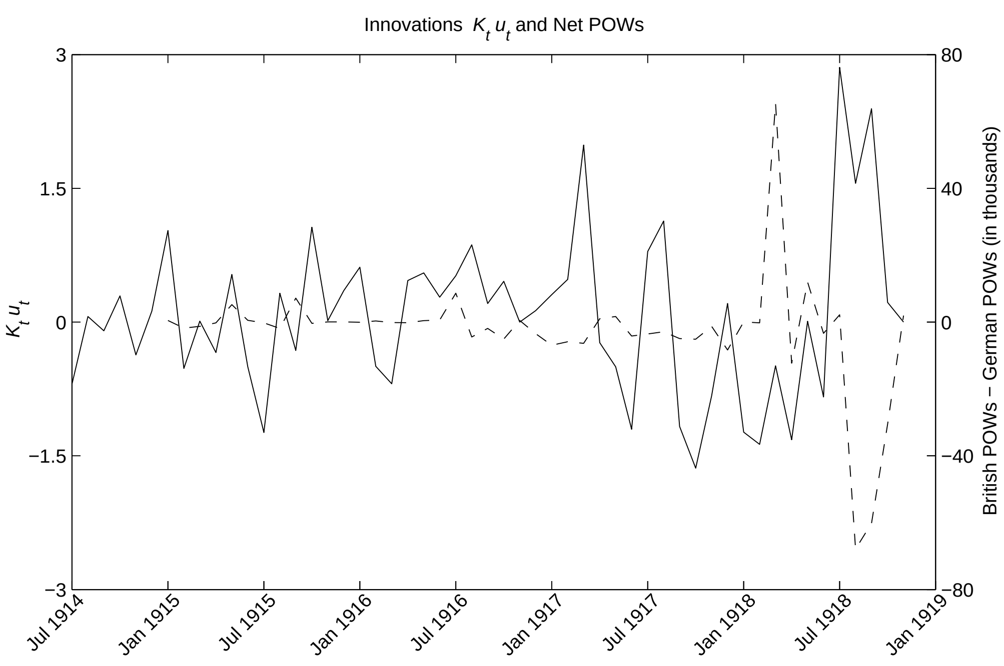

Figure 12: Innovations to the common factor, $K_t u_t$, (solid line, left axis) and net POWs (dashed line, right axis).

	German calorie intake	U.K. meat consumption	U.K. bread & flour consumption	U.K. shipping losses
$\hat{x}$	-0.07	0.43	0.02	0.13
$\mathcal{K}_t u_t$	-0.62	-0.06	0.02	-0.05
$u^{Britain}$	-0.57	0.07	-0.03	-0.09
u^{France}	-0.57	-0.02	-0.02	0.03
u^{Italy}	-0.75	-0.26	0.06	0.12
$u^{Austria}$	0.44	0.19	-0.13	0.25
$u^{Germany}$	0.24	0.21	-0.08	0.00

Table 7: Correlation Coefficients between Consumption and Shipping Data and Series Imputed from the Five-Country Factor Model

German calorie intake is the mean daily per capita calorie intake from a set of thirty surveyed households in Leipzig, standardized for age, sex, family size and work performed. The data are monthly from March 1917 to November 1918. Source: Offer (1989) *The First World War: An Agrarian Interpretation*, page 50.
Consumption of bread and flour in the United Kingdom are monthly index numbers of retailer's sales from June 1916 to November 1918. Source: Beveridge (1928) *British Food Control*, page 366.
Consumption of butcher's meat in the United Kingdom are monthly index numbers of retailer's sales from January 1916 to November 1918. Source: Beveridge (1928) *British Food Control*, page 367.
War Losses of British shipping are monthly losses in gross tons from August 1914 to November 1918. Source: Fayle (1927) *The War and the Shipping Industry*, page 417.

> of German POWs. ... The Germans too produced postcards and newsreels showing foreign prisoners of war being marched through German cities.

This difference between how killed and wounded and POWs were interpreted suggests that the number of POWs taken is highly correlated with morale and the willingness of soldiers to continue fighting. Unlike being killed and wounded, to be taken prisoner often involved a choice.[20] A soldier could often (but not always) decide whether or not to surrender. This was not usually the case for being killed or wounded. Furthermore, taking an enemy prisoner was arguably better than killing or wounding him. Wounded soldiers were often returned to the front after their injuries healed. Prisoners on the other hand were sources of intelligence and could perform work for the captor. As figure 9 shows even during the last half of 1918, the net body count was still in the German's favor; but as figure 10 illustrates German soldiers were giving up in unprecedented numbers. In terms of killing and wounding, the German army was still more effective than the Allies. (And again note figure 9 does not include the number of American soldiers killed and wounded.) Never the less – in terms of prisoners of war – there was no doubt in second half of 1918 that the Germans were losing.

[20]See chapter 13 of Ferguson, 1998, for a nice discussion of the issues surrounding surrendering.

	German calorie intake	U.K. meat consumption	U.K. bread & flour consumption	U.K. shipping losses
$\hat{x}$	-0.17	0.45	0.00	0.01
$\mathcal{K}_t u_t$	-0.43	-0.36	0.16	-0.13
$u^{Britain}$	-0.58	-0.03	0.01	0.03
u^{Italy}	-0.73	-0.36	0.09	0.10
$u^{Austria}$	0.32	0.34	-0.21	0.23
$u^{Germany}$	0.16	0.32	-0.02	0.00

Table 8: Correlation Coefficients between Consumption and Shipping Data and Series Imputed from the Four-Country Factor Model

German calorie intake is the mean daily per capita calorie intake from a set of thirty surveyed households in Leipzig, standardized for age, sex, family size and work performed. The data are monthly from March 1917 to November 1918. Source: Offer (1989) *The First World War: An Agrarian Interpretation*, page 50.
Consumption of bread and flour in the United Kingdom are monthly index numbers of retailer's sales from June 1916 to November 1918. Source: Beveridge (1928) *British Food Control*, page 366.
Consumption of butcher's meat in the United Kingdom are monthly index numbers of retailer's sales from January 1916 to November 1918. Source: Beveridge (1928) *British Food Control*, page 367.
War Losses of British shipping are monthly losses in gross tons from August 1914 to November 1918. Source: Fayle (1927) *The War and the Shipping Industry*, page 417.

Relative to the Allies, Germany had a more difficult time growing and importing enough food to feed its population during the war. Some have argued that given Germany's success on the battlefield as measured by the net body count, Germany did not lose the war militarily but was starved into defeat.[21] Therefore I examined the average calorie intake from a sample of households in Germany, two measures of food consumption in Britain, and British shipping losses due to the war. In tables 7 and 8, I report the correlation coefficients between these series and the imputed innovations and $\hat{x}_t$ series. German calorie intake is negatively correlated with the innovations implied by the two models. At first glance, it appears that calories were as important as casualties to contemporaries forecasting the duration and outcome of the war; but this result is hard to interpret since German calorie intake is much more correlated with Allied innovations than with German innovations. Furthermore U.K. meat consumption has the same basic correlation pattern as German calorie intake: negatively correlated with Allied innovations, positively correlated with the Central Power's innovations. If currency traders were using data from the home-fronts to adjust their expectations about the war, I cannot explain why these two series would have the same correlation pattern. In contrast, consumption of bread and flour in the U.K. is uncorrelated with all of the imputed series. Finally, U.K. shipping losses are also

[21] See the first five chapters of Offer, 1989.

uncorrelated with all the imputed series. U.K. shipping losses rose steadily during the first half of the war, peaking in early 1917; after this peak, shipping losses steadily declined. This time series pattern does not correspond to the pattern in the innovations or the $\hat{x}_t$ series.

It is often argued that the First World War was a time of large government interventions in foreign exchange markets. While there are numerous examples of various government attempts to control the value of their currencies, the results presented here illustrate that these attempts were not entirely successful. During the war all five of the currencies depreciated relative to the Swiss franc despite a doubling of the Swiss price level. Furthermore, as in other wars, currencies of the opposing countries moved in opposite directions depending on news of military events. This provides another illustration that the value of currencies respond predictably to non-monetary events, and in particular to events that help forecast future government surpluses.

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