How Much SRISK Is Too Much?

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Abstract

When financial firms are under-capitalized, they are vulnerable to external shocks. This is commonly measured by stress tests or market-based measures of systemic risk such as SRISK. The natural response to such vulnerability is to raise capital and this can endogenously start a financial crisis. Excessive credit growth can be interpreted as under-capitalization of the financial sector. Hence, we can assess how much SRISK an economy can stand, and measure the probability of a crisis. Using a crisis intensity variable constructed by Romer and Romer (2017), we estimate a Tobit model for 23 developed economies. We develop a *probability of crisis* measure and an *SRISK capacity* measure from the Tobit estimates. These reveal the important global externalities since the risk of a crisis in one country is strongly influenced by the under-capitalization of the rest of the world.

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1 Introduction

When financial institutions are under-capitalized, they are vulnerable to external shocks. Even more importantly, however, they may become the source of these shocks through normal economic behavior. When under-capitalization is extreme, these endogenous shocks become sufficient to cause an economic downturn which we call a financial crisis. In this paper, we develop and estimate a model of the impact of under-capitalization on the *probability of crisis*. This model can be solved to obtain a corresponding *SRISK capacity* which would keep this probability below 50% as long as SRISK remains below this level.

It is widely believed that financial crises result from *excessive* credit growth. See, for instance, Reinhart and Rogoff (2009), who claim that this time is *not* different, Borio (2014) and Drehmann, Borio, and Tsatsaronis (2012) on financial cycles, Adrian and Shin (2010, 2014) on leverage cycles and Schularick and Taylor (2012) on the predictive power of credit growth. However, the challenge is how to measure excessive credit growth. We will argue that credit growth is excessive if the financial sector does not have sufficient reserves to cover market value losses in a downturn. This is consistent with the notion that at the end of a credit cycle, increasingly risky credit will be issued and the holders of this credit will be leveraged financial institutions with insufficient reserves to cover losses in a downturn. In this way a "credit boom goes bust." We estimate the dollars that a financial firm would need to raise in order to function normally if we have another financial crisis. This is a widely used measure called SRISK which is computed weekly and published on NYU Stern's Volatility Laboratory (V-Lab).[1] It measures capital shortfall under stress and is similar to a regulatory stress test. It was initially introduced in Acharya, Brownlees, Farazmand, and Richardson (2011) and Acharya, Engle, and Richardson (2012), and then expanded in Brownlees and Engle (2017). These dollars of capital shortfall can be

[1]See `https://vlab.stern.nyu.edu/welcome/risk/`.

summed for an entire financial sector to provide a measure of systemic risk.

When SRISK is high, either the regulator or the risk manager of individual companies will compel the firms to strengthen their balance sheet. This can be done in many ways but the most commonly used approaches lead to sales of assets or equity. When such sales are in large volume, it is inevitable that there will be a price impact which is commonly called a "fire sale externality." This leads to a downward spiral of the financial sector and ultimately of the economy that has been written about extensively. See for example Cont and Schaanning (2016), Greenwood, Landier, and Thesmar (2015), Pedersen (2009) among others. The initial conditions that make such a fire sale likely are precisely a large quantity of goods to be sold in a hurry without a large collection of willing buyers.

Using crisis severity measures created by Romer and Romer (2017), we estimate the level of under-capitalization that precipitates a financial crisis. We examine 23 developed economies over time and seek a quantitative measure of the probability of a crisis as a function of the aggregate capital shortfall and other variables. We can then compute *SRISK capacity*.

Although we focus on the downward spiral in a fire sale, a similar process can be seen in the upward direction. Ruan (2017) calls this the "race to the Top." Deregulation in this context allows financial institutions to increase their risk and leverage thereby making the system more likely to have a financial crisis in the future, although less likely in the short run. Thus, the models here are essentially a theory of endogenous financial cycles.

This model of systemic risk features two widely recognized externalities. The risk of a financial crisis in a country depends upon the total capital shortfall of the financial sector in this country. Thus, a single risky firm will not be systemic unless it is extremely large. Any firm that reduces its capital shortfall will benefit all firms and the economy as a whole. Similarly, the risk of one country depends upon the aggregate SRISK of the rest of the world. Hence, a country that improves its regulation or reduces its financial sector under-capitalization, will benefit other countries and global financial stability. This setting clearly requires regulation and cooperation to achieve optimal performance.

The paper that is closest to estimating aggregate crisis probability is Adrian, Boyarchenko, and Domenico (2016). They examine how financial conditions in the US affect US GDP and discover that weak financial conditions lead to a risk of GDP downturns. However, they do not calculate the probability of a financial crisis or motivate the use of the broad financial conditions index which is composed of more than 100 series. And because they only examine the US and use this index, they do not incorporate either of these externalities.

The paper proceeds as follows: Section 2 motivates our measure of excessive credit. Section 3 introduces SRISK and discusses details of its construction. Section 4 describes the mechanism that generates fire sales and suggests measures of the intensity of such a spiral. Section 5 describes data and the crisis measure of Romer and Romer (2017). Section 6 gives empirical results on the level of SRISK that induces a financial crisis, and section 7 discusses the results. Section 8 concludes.

2 Excessive Credit Growth

In order to implement this model, we must distinguish between productive credit growth and excessive credit growth. As credit typically grows with output, various measures of excessive growth have been proposed focused on whether it grows much faster than output. Instead, we focus on the quality and risk of firms extending and ultimately holding credit.

Consider a simple example of a bank that holds mortgages. This bank may eventually at the end of a credit cycle, lend to underqualified borrowers and overvalued houses. In this case, the mortgages will actually be worth less than the accounting values and the bank's ratio of market value to book value will fall. This can be seen in the equity value of the firm as well as mark to market valuation of the loans. If there is a downturn in the housing market, the value of the mortgages will fall further as the collateral loses value and the borrowers become weaker. The firm may have to cover these losses from its reserves, and if the reserves are inadequate, the value of the assets of the bank may fall below its liabilities. In this case, stock market valuation will collapse, and the bank may seek a bailout in order to continue functioning. Thus excessive credit growth can be measured by the capital shortfall of the financial sector.

From this example, it is natural to examine the valuation of financial sector assets relative to their liabilities. If the assets are undervalued and risky, we would expect to see low ratios of market to book and high equity volatility. If this is a systemic problem as opposed to a single firm we would expect to see high correlations with market-wide events. This is measured by the beta of the firm. In a stress scenario, the broad market will decline, and the impact on capital at each firm will depend upon its beta. And in fact, the betas will differ depending upon the asset holdings as the market is well aware of these effects.

Thus the task is to estimate the capital that would be needed under stress for each firm in order to continue to operate.

3 SRISK

In a series of papers, Acharya et al. (2011, 2012) and Brownlees and Engle (2011, 2017) have introduced a measure of financial under-capitalization that can be interpreted as indicating systemic risk. SRISK is the dollars that a financial firm would need to raise in order to continue to function normally if we have another financial crisis like the last.

Because it is difficult to raise capital in a financial crisis, this capital shortfall will either be met by the taxpayer or the firm will cease to function normally and may fail. For this reason, the measure is considered to be an indicator of systemic risk in much the same way as are supervisory stress tests.

The exact calculation takes several steps.

1. Normal operation under stress conditions requires that market value of equity divided by quasi-assets (book value of liabilities plus market value of equity) be above a minimum level. We typically use 8% which is equivalent to a total leverage ratio of 12.5 to one. This value corresponds to typical leverage ratios of well managed financial firms in tranquil periods.[2,3] The shortfall is computed as

$$Capital\ Shortfall = k\left(Debt_{t+T} - Equity_{t+T}\right) - Equity_{t+T} \tag{1}$$

where T is taken to be six months in the future. The notional value of liabilities is not likely to change with the stress but the value of equity will.

2. To forecast the Capital Shortfall, we use a standard financial approach, the market regression.

$$r_t^f = \beta_t^f R_t^M + \varepsilon_t^f \tag{2}$$

where r_t^f is the equity return on day t for firm f. Similarly, R_t^M is the world market return taken to be the return on the MSCI ACWI ETF. Both returns are measured as continuously compounded or log returns. This model could be estimated assuming beta is constant, and that the residual variance is constant. However, we will relax these assumptions.

This relation captures the market view of the rate at which falling asset values lead

[2] In June 2017 for example the average of the six largest US bank leverage ratios was 9.1, in June 2014 it was 11.3, in June 2010 it was 15.5, and in June 2005 it was 9.5. The average of these is 11.3 or slightly less leverage than used in SRISK. Users of V-Lab have the option of setting the capital ratio at any desired level.

[3] Firms using IFRS accounting rather than GAAP have typically a bigger balance sheet as there is less netting of derivatives. Consequently, we use 5.5% for all European firms.

to equity declines when the market collapses. It explicitly focuses on the comovement of this firm and the market, rather than just the volatility of the firm. This is why this is a macroprudential measure of risk rather than microprudential.

Letting p_t^M and P_t^M be the prices at the end of day t,

$$\begin{aligned} \frac{p_{t+T}^f - p_t^f}{p_t^f} &= \exp\left(\sum_{j=1}^{T}\left(\beta_{t+j}^f P_{t+j}^M + \varepsilon_{t+j}^f\right)\right) \\ &\approx \exp\left(\left(\beta_t^f\right)\left(\log\left(P_{t+T}^M / P_t^M\right)\right)\sum_{j=1}^{T}\left(\varepsilon_{t+j}^f\right)\right) \end{aligned} \tag{3}$$

The approximation here is that the betas and gammas have almost a unit root, so the forecasts over the next six months are essentially the same as today. Hence the regression coefficients can be factored out of the sum. An alternative simulation approach has been implemented in Brownlees and Engle (2011, 2017) and in V-Lab's MESSIM. The fractional return is a random variable, and we will consider the median conditional on a stressed market return. Assuming the idiosyncratic errors to have median zero, the median fractional change in equity prices in a crisis is

$$Median\left(\frac{p_{t+T}^f - p_t^f}{p_t^f}\right) = \exp\left(\left(\beta_t^f\right)\log\left(1-\theta\right)\right) \tag{4}$$

where

$$\frac{P_{t+T}^M - P_t^M}{P_t^M} = -\theta \tag{5}$$

Often the six-month return on the firm equity is called 1-LRMES which is the Long Run Marginal Expected Shortfall. If the market falls 40%, the firm may have a beta bigger than one and so will expect an equity decline of perhaps 50% which is the LRMES.

For firms located in different time zones, part of the response will appear to be from the previous day return. Hence

$$r_t^f = \beta_t^f R_t^M + \gamma_t^f R_{t-1}^M + \varepsilon_t^f \tag{6}$$

The six-month forecast of returns on a firm when the market declines by θ is then computed using formula 4 with the sum $\beta_t^f + \gamma_t^f$ replacing the beta.

3. The parameters beta and gamma are estimated by the Dynamic Conditional Beta model as described in Engle (2016). This approach recognizes that a regression coefficient is a product of a correlation between the firm return and the market return times the ratio of the standard deviation of the firm return and the market return. All three of these values are potentially time varying and can be estimated by GARCH and DCC. The same argument can be applied to gamma under the assumption of no autocorrelation in the market return.

It is natural to test the hypothesis that the betas are constant. As this not a nested hypothesis, a useful strategy is to construct an artificial model that nests both the constant beta and DCB. The nested model can be expressed as

$$r_t^f = \left(\phi_1 + \phi_2 \hat{\beta}_t^f\right) R_t^M + \left(\phi_1 + \phi_2 \hat{\gamma}_t^f\right) R_{t-1}^M + \varepsilon_t^f \tag{7}$$

where $\hat{\beta}$ and $\hat{\gamma}$ are computed from the GJR-GARCH estimates of firm and market volatility and a DCC estimation of the correlation. This model can be estimated assuming a GJR-GARCH error term to give estimates of the four coefficients. We would expect $\phi_2 = \phi_4 = 0$ for beta constant or $\phi_1 = \phi_3 = 0$, $\phi_2 = \phi_4 = 1$ for DCB. Typically, both hypotheses can be rejected which means that some combination of constant and time-varying beta is favored by the data. Hence, we use these estimates with $\left(\hat{\phi}_1 + \hat{\phi}_2 \hat{\beta}_t^f\right)$, and $\left(\hat{\phi}_3 + \hat{\phi}_4 \hat{\gamma}_t^f\right)$ as the final estimates of β_t^f and γ_t^f.

In the formula for SRISK, we envision the stress lasting six months, so both beta and gamma are equally important and just sum together. Letting

$$\tilde{\beta} = \left(\hat{\phi}_1 + \hat{\phi}_2 \hat{\beta}_t^f\right) + \left(\hat{\phi}_3 + \hat{\phi}_4 \hat{\gamma}_t^f\right) \tag{8}$$

$$SRISK_t = kDebt_t - (1-k)Equity_t \exp\left(\tilde{\beta}\log(1-\theta)\right) \tag{9}$$

4. The market variable used in SRISK is the global market ETF. As this is traded in the US, the closing price is the price at the NY close, and it reflects the information that agents know at that time. During the financial crisis, this measure declined approximately 40% over six months. Thus, we take this to be the stress for calculating SRISK, however a V-Lab user can set the stress level wherever it is desired. By using a one-factor stress, we reduce the possibility that we will miss the cause of the next financial crisis. Whether the crisis is caused by a housing market collapse, sovereign debt collapse, commodity price collapse, exchange rate collapse, government shut down or derivative market failure, the stock market is probably going to fall in anticipation of a decline in the real economy. It is almost inconceivable that a financial crisis could occur without a substantial fall in the stock market.

Interestingly, the firm betas reflect the characteristics of the crisis and their impact on each firm. For example, in the Great Recession, the beta of Bank of America and Citigroup rose to 3 and 4 while neither Goldman nor BNP Paribas moved much at all. They were not involved in the subprime mortgage business. However, in the European Sovereign Debt Crisis, Credit Agricole and BNP's betas rose almost to three as these banks were very exposed to Greek and other peripheral country debt.

5. Aggregate SRISK is the sum for a country of all the financial firms with positive values. This is the sum of all the institutions that would have to raise capital in a crisis. We do not net the overcapitalized firms as the capital from these prudent firms is not immediately available to recapitalize the weak firms. Mergers do happen, but more often, the well-capitalized firms protect their reserves as bad events are approaching.

4 Deleveraging Cycles

It is widely appreciated that deleveraging by financial institutions may induce an economy-wide downturn. The mechanism is essentially that when the financial sector is deleveraging, the real economy will be starved for credit and will contract. There are many ways firms can reduce leverage. In this paper, we consider three. Corresponding to each approach, there is a natural measure of the severity of systemic risk. When firms are urged to reduce their systemic risk either by risk managers or by regulators, they can do nothing and wait for growth to increase their equity and if it doesn't, appeal for a bailout. A second alternative is to sell new shares of stock (or equivalently reduce dividends). The third strategy is to sell existing assets and use the proceeds to reduce debt.

If firms choose to do nothing, then the cost to the regulator is the loss of GDP that would be required in a bailout. Thus, the natural measure of the size of the risk is SRISK/GDP. When this ratio is high, the risk is very high if firms choose this strategy. If firms choose to sell new shares to raise capital or reduce dividends, they may lower the values of existing shares. That is partly a signaling effect whereby the signal that the bank must raise capital conveys information that the firm is in trouble. It may also simply be a supply and demand effect where the more shares are in existence, the lower the price. In either case, the larger the volume of shares that needs to be sold, the bigger this effect. Hence if the value of shares that need to be sold is a large fraction of the shares that are already outstanding, the price impact is likely to be large, and firms will hesitate to use this channel. Hence a natural measure of excessive risk is SRISK/MV where MV is the market capitalization.

If the firm chooses to sell assets and the total amount contemplated is small compared with the stock of assets, then asset sales are likely to be cost-effective. Thus, financial institutions may choose between these approaches depending upon the ratio of assets to market cap in the financial sector as a whole. This measure of leverage would imply that firms would be more likely to raise equity when leverage is low and sell assets when leverage is high. Since financial crises often coincide with periods of high leverage, the sale of assets is a common approach.

Asset sales have a damaging feature that has been widely discussed. Large asset sales are likely to depress the price of assets which will in turn increase the leverage of all financial firms holding similar assets. This is often called a leverage spiral which means that deleveraging by selling assets may even be counterproductive in the extreme but at minimum will require more sales than initially anticipated. Frequently this leverage spiral is called a "fire sale" and may lead to asset sales at prices below their fundamental value. However, the same phenomenon is called price impact in market microstructure and is a description of expectations that are reduced by observations of selling pressure. In this case, the price is depressed because market participants reduce their expectations of future value.

In either context, there are many sellers and insufficient quantities of motivated and well-capitalized buyers to prevent price declines. As a consequence, firms experience a capital loss on assets. Investors can see this prospect and will reduce their equity valuations in advance of the mechanical process of selling assets. Similarly, the real economy that depends upon credit extended by the financial sector will find that they are competing with the small number of buyers for financial assets leading to excessive costs of credit. Furthermore, the negative expectations of the economic future extracted from the asset selling will also make borrowers look increasingly risky. Just when enterprises need capital, the financial markets will deny it.

The natural risk measure if firms choose to deleverage by selling assets is, therefore, the ratio of assets for sale over total assets. This can be computed analytically for the financial sector as a whole if there is no price impact. In order to reduce SRISK to zero,

A^{sales} of assets are sold and debt is retired. If there is no price impact, there would be no effect on equity, therefore

$$0 = k(Debt_t - A^{sales}) - (1-k)Equity_t \exp\left(\tilde{\beta}\log(1-\theta)\right) \tag{10}$$

$$A^{sales} = SRISK/k \tag{11}$$

Thus the natural measure of the size of SRISK which is dangerous is SRISK/(Total Assets/k) which is interpreted as A^{sales}/A^{total} and will be denoted by SRISK/(TA*k).

Interestingly, as Ruan (2017) has pointed out, this leverage spiral can work in reverse. She calls this the "race to the top" and reflects the fact that when financial firms have excess capital, they can build leverage by buying assets and incurring price impact. In this case price impact is a positive contribution to firm value and investors will presumably recognize this in advance as well. In this situation, firms appear well capitalized but have rising leverage. This is an explanation for the market valuations of financial firms before the financial crisis and maybe also after the Trump election.

5 Data on Three Measures of SRISK

Data on SRISK/GDP, SRISK/MV, and SRISK/TA varies across countries and over time. Recent snapshots of these aggregate statistics are given in Figures 1, 2 and 3 which show the countries with the highest values of each measure. Notice that Japan is the highest for all three measures, although this has not generally been the case. We see that the capital shortfall of Japan is about 15% of GDP so the cost of bailing out the banks in another financial crisis would be enormous.

In Figure 2, the new capital that would be needed by these institutions is roughly 100% of the current market value of the firms. Hence, the stock market value of these firms would need to double through selling new shares in order to eliminate the capital shortfall. Selling this volume of new shares would surely depress the price substantially especially if undertaken in a crisis.

Finally, the ratio of SRISK to total assets in Japan is a little over 5%. Since the capital ratio is 8% for Japan, this means that 5/8 of the financial sector assets would need to be sold in order to reduce SRISK to zero. Again, this is likely to start a severe fire sale in assets which will reduce their market value substantially through the price impact of the sales. Furthermore, firms that are selling assets such as corporate loans or mortgages will be unlikely to issue new credit and therefore there is likely to be substantial credit disruption.

6 How Much SRISK Is Too Much?

To compare these three measures as indications of how much SRISK is too much, we use the Romer and Romer (2017) crisis indicator. This is a carefully constructed measure not only of whether there is a financial crisis, but how severe is the crisis. For each country and for every six months they read the OECD Economic Outlook and classified the nature of any financial crisis. The primary feature that they say makes this a financial crisis is a disruption in credit supply. Their measure of crisis intensity is on a scale of 1 to 15 which goes from a "credit disruption minus" to "extreme crisis plus." These measures are constructed for 24 developed economies and include the period 2000 to 2012. If there is no crisis, the measure is zero; if the measure is greater than 3, it becomes more than a "minor credit disruption."

We use these crisis measures for 23 of their countries. We do not include Iceland because it still does not have any publicly traded banks. During the Global Financial Crisis, all of them failed. We average the monthly SRISK figures over each six month period for each of the countries. The Crisis data is shown for all countries in Figure 4. As can be seen there are substantial differences across countries. For most countries, there is a peak in 2008/9 but in some it continues to rise and for others there was a financial crisis in 2002/3 as well. For some, the crisis is more severe than for others.

The goal is to explain the time series and cross sectional measures of crisis severity with these systemic risk measures. In this way, we can learn how much SRISK is associated with a crisis.

The first model is a panel regression of this crisis measure on the three SRISK measures including time and country fixed effects. In Table 1 the first column shows that the most useful variables are SRISK/(TA*k) and SRISK/MV as the measure divided by GDP is negative. The negative sign could be due to regulatory forbearance when the costs of a bailout are very high.

The remaining columns replace the time fixed effects with various measures of world capital shortfall. The results are similar to the fixed effects model and show that some measure of world SRISK is correlated with the time fixed effects.

Running the same regression as a predictive regression (Table 2) reinforces this conclusion. With a lagged dependent variable and fixed effects, SRISK/(TA*k) remains significant. However, with measures of world SRISK, its significance is reduced.

The regression does not take account of the fact that more than half of the dependent variable observations are zero. The relation between crisis severity and SRISK is naturally a hockey stick rather than a straight line. In fact, the preferred estimator for this model is a Tobit which recognizes that the dependent variable is truncated at zero. The estimate also allows the possibility that countries will differ in the tolerable level of SRISK by including country fixed effects. This may be due to institutional markets for selling assets and pools of investors who might be willing to step in even as a crisis is approaching. It may also be due to differences in the likelihood of a government rescue that would protect both financial firms and those buying assets.

A Tobit model is defined in terms of a latent variable y_l which depends upon explanatory variables X and a disturbance. The observed dependent variable, y, is a truncated version of y_l. Under the assumption that the error term follows a standard normal distribution, the model can be expressed by two equations as follows:

$$y = \begin{cases} y_l \text{ if } y_l > 0 \\ 0 \text{ otherwise} \end{cases}$$

$$y_l = X\beta + \sigma\varepsilon,\ \varepsilon \sim \mathcal{N}(0,1)$$

From this model, we can compute the probability that the dependent variable will exceed a value $q > 0$ conditional on X.

$$\Pr(y > q|X) = \Pr(y_l > q|X) = \Pr\left(\varepsilon > \frac{q - X\beta}{\sigma}\middle| X\right) = 1 - \Phi\left(\frac{q - X\beta}{\sigma}\right) \tag{12}$$

A Tobit model with fixed effects is given in Table 3. Here, the world SRISK variables are calculated using leave-one-out sums of respective SRISK variables. The SRISK/(TA*k) variable is highly significant and so are many of the country dummies. This has the best Schwarz criterion of any of the models including many not reported here.

To calculate the probability of a crisis we can calculate the probability that Crisis is greater than some threshold such as 4 which is a mild crisis under the Romer system. Substituting values for $\left(\hat{\beta}, \hat{\gamma}\right)$ in equation (12) and constructing the data matrix X which is a six month moving average of SRISK and its related measures, we compute a monthly value for the probability of crisis. R Furthermore, we can ask whether there is a level of SRISK that makes the probability of a crisis just 50%. From 12 we see that the probability of a crisis is a half when $X\hat{\beta} = 4$. We can solve for a *SRISK capacity* that corresponds to this level of risk. Here $\hat{\beta_1}$ is the estimated coefficient on SRISK/(TA*k) in the Tobit estimation. Notice that in the country model given as equation (1) this is the sum of the first two coefficients or 18.179+6.822.

$$SRISK\_CAPACITY = SRISK + \frac{4 - X\hat{\beta}}{\hat{\beta_1}} \times k \times TA \tag{13}$$

This capacity can be measured monthly by interpreting X as the moving average of the observable variables from the Tobit regression.

The estimated fixed effect for each country is tabulated in Table 4. For equation 2 which includes world SRISK/(TA*k) and its change as well as country SRISK/(TA*k), the fixed effect reflects the resistance to crisis with equal values of SRISK. These range from -17.9 for Belgium to -5.5 for Turkey. Thus, with equal characteristics, Turkey is much more likely to have a crisis than Belgium. Interestingly, Japan is in the middle at -10.1.

7 Results and Discussion

From these regressions, we compute the probability of crisis and the *SRISK capacity*. The probability of crisis is computed for both the domestic model (Column 1) and the global model (Column 2) from Table 3. Similarly, the *SRISK capacity* is tabulated for both equations and plotted with country SRISK. Figure 5 and 6 plot these two measures for the US. Similar charts are included for all countries studied by Romer and Romer (2017) with the exception of Iceland in the Appendix: Measures for Other Countries.

From Figure 5, we can see that the domestic and global models give rather similar estimates for the probability that the US is in a crisis over the 17 year period although the peaks are a little higher in the global model. In 2008 the probability rises to 80% or

90% whereas it is only about 60% in the European sovereign debt crisis and in the recent period has fallen to less than 10%. In contrast, many of the European countries had a greater peak in 2011 than in 2008.

Figure 6 gives more information on the systemic risk in the US. The solid line is the SRISK for the US. Whenever this exceeds the capacity, the probability of crisis rises above 50%. Notice that the dashed line is rising over time indicating that the capacity of the US to avoid a financial crisis is rising, and in this case it is a result of the increase in total assets in the financial sector.

Notably, the *SRISK capacity* obtained from the global model dives in 2008–09 making a crisis in the US more likely. Similarly, it declines dramatically in 2011-12 and 2016. These three incidences, not unique to the US, correspond to the three crisis episodes since 2000 and reflect the global nature of a financial crisis. Let us briefly review these three episodes and summarize their common features to emphasize the importance of capturing this nature.

The time series dynamics of world SRISK since 2000 (Figure 7) reveals three peaks. The magnitude of the peak is close to $4 trillion in each case and greatly exceeds the SRISK during the first seven years of this century. The first two peaks correspond to two well-known crisis episodes, the Global Financial Crisis and the European sovereign debt crisis. The third peak in 2016–17 might be called the Asian debt crisis with Japan and China as the two biggest contributors. What is common in all three episodes is that banks massively increase their holdings of perceived riskless debt and subsequently experience stress in one or at most a handful of countries, and such financial stress spreads from these countries to other countries.

The first episode, the Global Financial Crisis, is widely perceived to be tied to the housing sector which experienced a rapid increase in the five years before the crisis. The housing price boom was fueled by a rapidly growing mortgage market that employed financial engineering and securitization to fund ever declining quality of mortgages from an international pool of investment capital. The magic of CDO (collateral debt obligation) securitization was that investors and ratings agencies and regulators all regarded the senior tranches as nearly riskless, regardless of the quality of the component mortgages. As the housing price started to fall, the previously neglected risks became apparent. SRISK of all US financial firms increased from the end of 2006 to August 2008, and such an increase was most substantial for the firms that were big participants in the mortgage market. European and Asian banks also needed capital as the crisis in the US escalated. In August 2008, there are 9 European banks with SRISK higher than Lehman.

In the second episode, the US equity markets responded to the emerging Greek sovereign debt crisis with the flash crash on May 6, 2010. SRISK in Europe increased more than 30% from the low of \$1,562 billion in the summer of 2009 to the peak of \$2,045 billion in Jan 2012. This rise corresponded to a collapse of sovereign bond prices of several Eurozone economies, particularly the peripheral countries, Greece, Italy, Portugal, Spain, and Ireland. These bonds were regarded as riskless by investors, rating agencies, and regulators. In the early European stress tests, there was no stress considered on sovereign debt and it continued to have zero risk weights. As many of the banks held large positions in these bonds, their equity valuation fell rapidly. As the local economies declined, the bank asset positions fell further and SRISK rose substantially. As the European financial sector deteriorated, the US continued to strengthen in part to the regulatory reform of the Dodd Frank Act. By January 2012, the US SRISK was down to \$689 billion. On the other hand, Asian SRISK continued to rise to \$1,183 billion in January 2012.

As SRISK has fallen dramatically in the US and more slowly in Europe, they have been rising in Asia. Japan and China are the two biggest contributors; they have pushed the world SRISK to a level similar to the previous two peaks. The rapid growth of Japans SRISK from 2013 to 2017 corresponds roughly to the monetary stimulus by Prime Minister

Shinzo Abe. Japanese banks hold sizable positions in Japanese Government bonds. These are discounted by financial markets leading to the large measure of under-capitalization. In China banks are mostly state-owned, and they extend credit to state-owned enterprises and local government agencies. It is worth noting that most Japanese and Chinese banks have low betas. That is, they do not appear to be particularly risky. The substantial leverage resulting from the low market-to-book ratios is the key driver of the high SRISK. In fact, the increase in liabilities is more than 100% of the increase in SRISK with some equity increase offsetting the increase in risk. Although the mechanisms are different, both China and Japan have rapidly rising debt levels and much of this debt is naturally viewed as riskless. In both cases, the majority of the debt is explicitly or implicitly guaranteed by the government. In neither country is there a crisis that looks like the Global Financial Crisis or the European sovereign debt crisis, but both countries have economic stress. Furthermore, the slowdown of the Chinese economy leads to dramatic declines in natural resource prices around the world and a commensurate increase in bank stress in natural resource rich economies.

The global model captures the important global externalities that the risk of a crisis in one country is strongly influenced by the rest of the world. Under-capitalization in one country will increase the probability of a crisis in another. The financial stability of countries are interconnected, and each has a stake in the regulation of the rest of the world.

8 Conclusion

We have estimated a model of systemic risk which is designed to show both the probability of a crisis and the distance between current measures of systemic risk and the level which makes the probability of crisis equal to a half. The model builds on the theory that deleveraging will have a price impact and the greater the magnitude of the deleveraging the more dangerous the adjustment. In its most extreme case, the real economy has restricted access to credit as the financial sector experiences a fire sale thus endogenously generating a financial crisis.

This paper quantifies this process with a simple model that incorporates systemic externalities both within countries and between countries. Countries can have a different tolerance for under-capitalization which appears in the model as a country fixed effect. Presumably this could be modeled as a function of institutions and global patterns of financial flows, but we leave this to future research.

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Figure 1: **SRISK/GDP by country in July 2017**

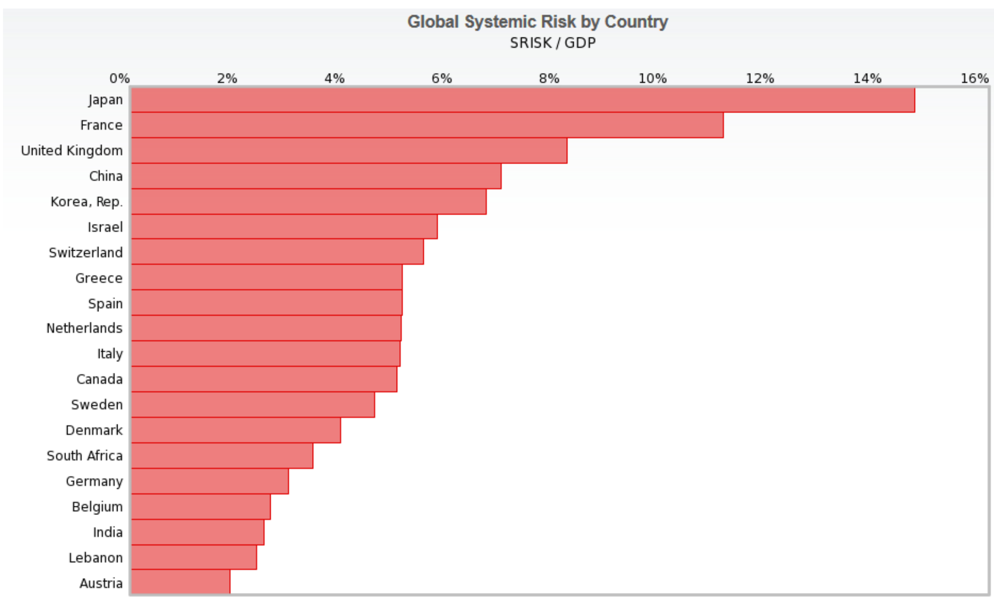

Figure 2: **SRISK/MV by country in July 2017**

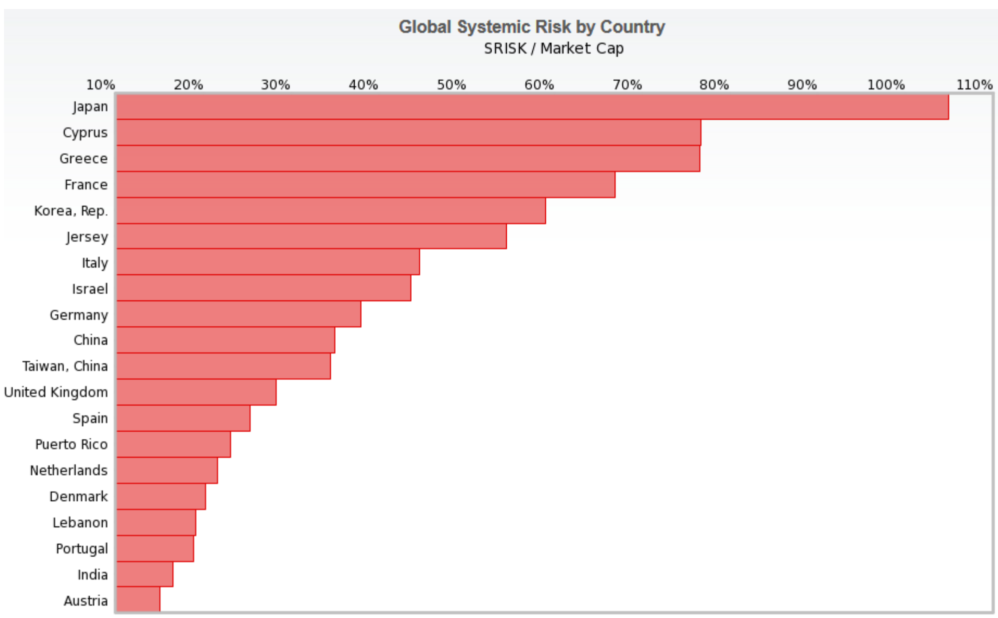

Figure 3: **SRISK/TA by country in July 2017**

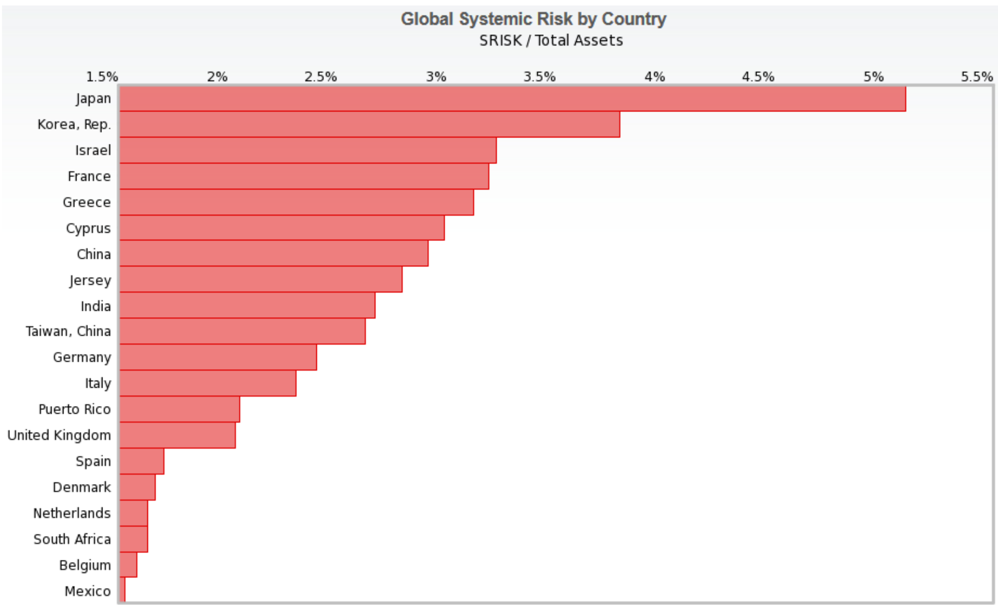

Figure 4: **Romer and Romer (2017) Crisis Intensity over time by country**

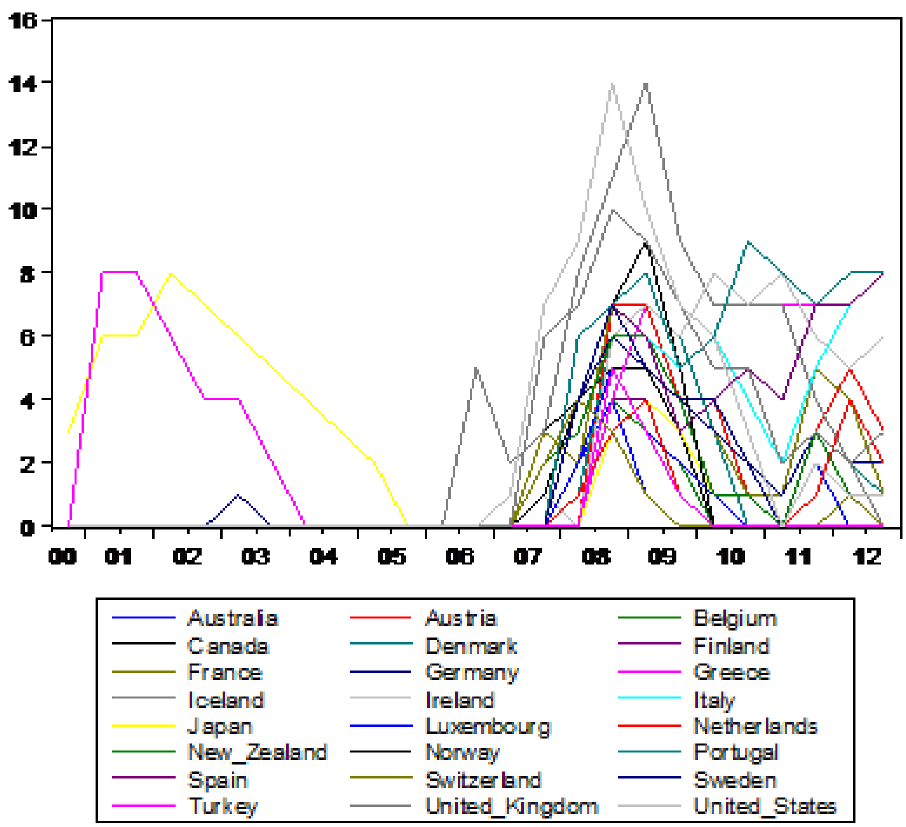

Figure 5: **Probability of Crisis (%): United States**

This figure plots the *Probability of Crisis* measures of the United States obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

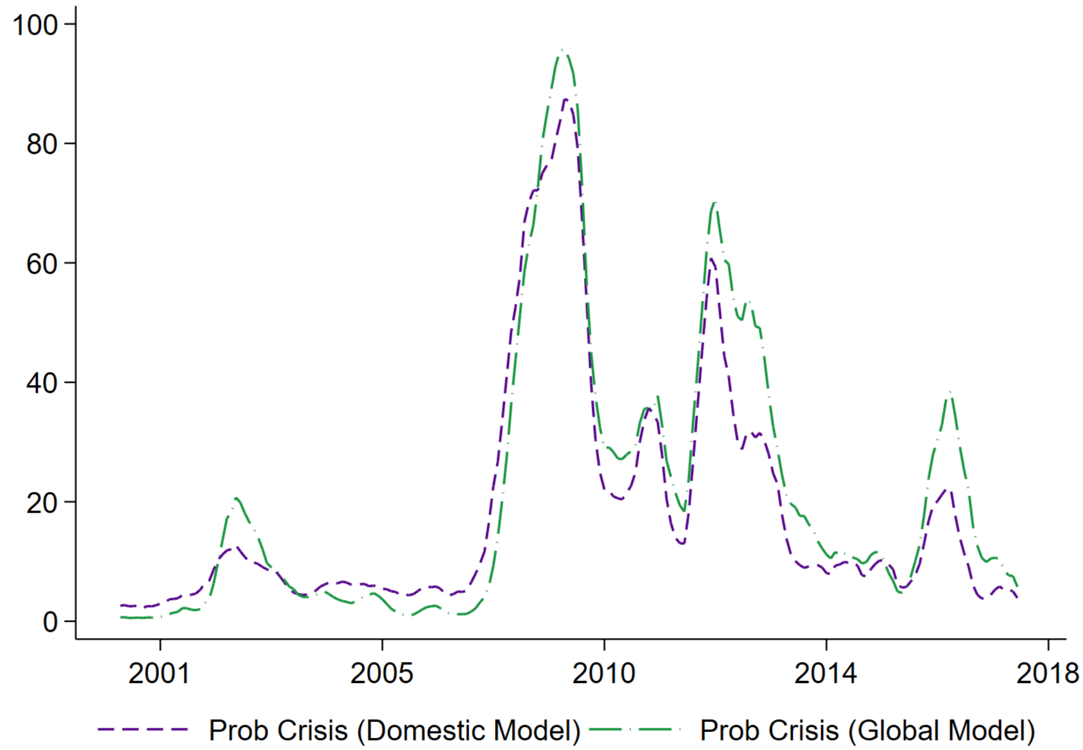

Figure 6: **SRISK Capacity (USD Million): United States**

This figure plots the *SRISK Capacity* measures of the United States obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

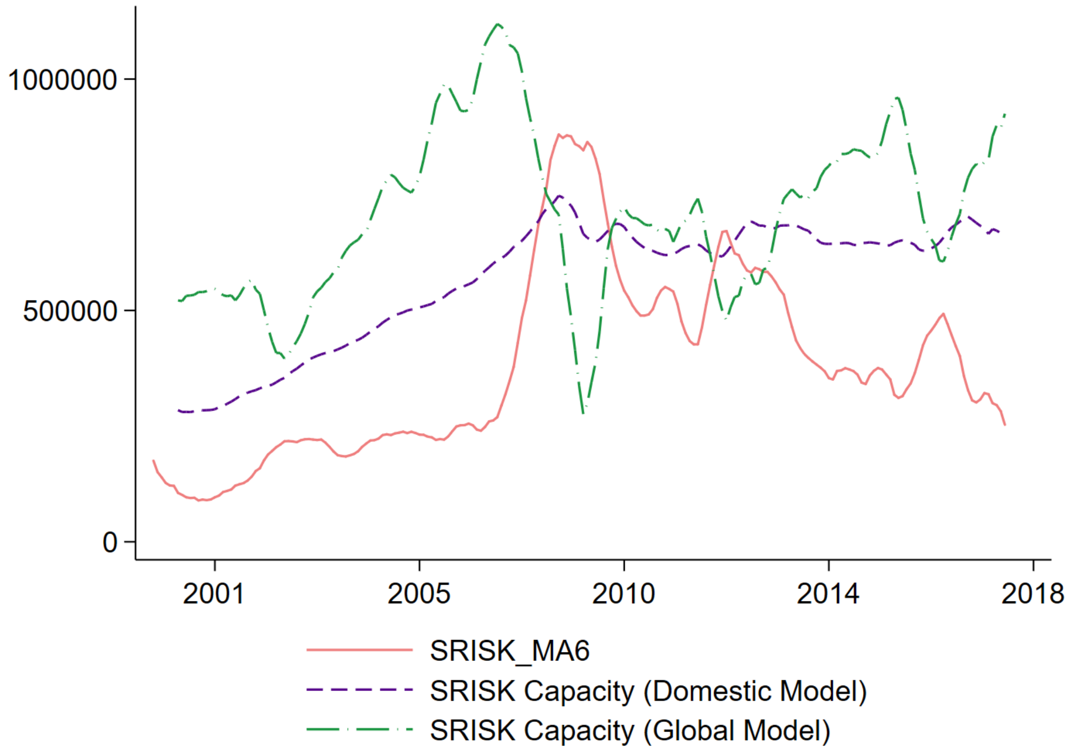

Figure 7: **World SRISK over time**

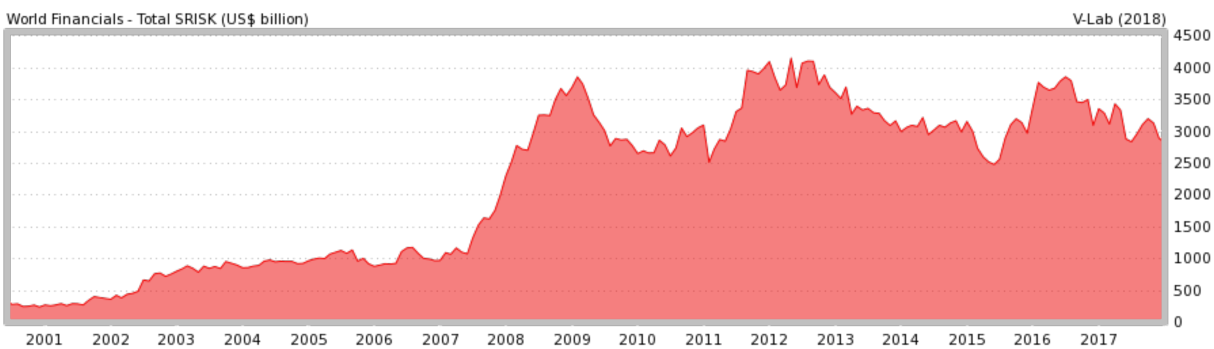

Table 1: **Crisis Severity and Systemic Risk Measures (OLS)**

This table reports the OLS estimates of how systemic risk measures are contemporaneously associated with crisis severity. The sample includes the all countries studied by Romer and Romer (2017) with the exception of Iceland from the second half of 2000 to the second half of 2012. The unit of observation is country-halfyear. The country fixed effects are included in all specifications. Standard errors are reported in parentheses. ***, ** and * represent 1%, 5% and 10% significance, respectively.

	Dep Var: CRISIS				
	(1)	(2)	(3)	(4)	(5)
SRISK/(TA*k)	5.401***	4.120***	3.653***	3.645***	5.172***
	(0.694)	(0.750)	(0.745)	(0.704)	(0.750)
SRISK/GDP	-0.226***	-0.276***	-0.295***	-0.289***	-0.276***
	(0.053)	(0.058)	(0.059)	(0.058)	(0.061)
SRISK/MV	0.480**	0.507**	0.738***	0.622***	0.761***
	(0.207)	(0.230)	(0.226)	(0.223)	(0.233)
World SRISK/(TA*k)		-8.380*	6.058***		
		(4.590)	(1.000)		
World SRISK/GDP		10.016			
		(20.124)			
World SRISK/MV		10.567***		5.381***	
		(2.562)		(0.761)	
World log SRISK					0.366***
					(0.134)
Time FE	Yes	No	No	No	No
Country FE	Yes	Yes	Yes	Yes	Yes
Within Country R^2	0.609	0.491	0.474	0.486	0.446
Overall R^2	0.650	0.544	0.530	0.540	0.477
Observations	564	564	564	564	564

Table 2: **Predictive Power of Systemic Risk Measures**

This table reports the OLS estimates of how systemic risk measures predict crisis severity. The sample includes the all countries studied by Romer and Romer (2017) with the exception of Iceland from the second half of 2000 to the second half of 2012. The sample size decreases relative to Table 1 due to the use of lagged variables. The unit of observation is country-halfyear. The country fixed effects are included in all specifications. Standard errors are reported in parentheses. ***, ** and * represent 1%, 5% and 10% significance, respectively.

	Dep Var: CRISIS			
	(1)	(2)	(3)	(4)
L.CRISIS	0.790***	0.843***	0.870***	0.825***
	(0.031)	(0.035)	(0.035)	(0.033)
L.SRISK/(TA*k)	1.347***	0.229	0.839*	-0.830*
	(0.426)	(0.499)	(0.478)	(0.480)
L.World SRISK/(TA*k)		-0.709		
		(0.841)		
L.World SRISK/MV			-2.076***	
			(0.650)	
L.World log SRISK				0.309***
				(0.105)
Time FE	Yes	No	No	No
Country FE	Yes	Yes	Yes	Yes
Within Country R^2	0.815	0.674	0.680	0.679
Overall R^2	0.836	0.710	0.715	0.714
Observations	541	541	541	541

Table 3: **Crisis Severity and Systemic Risk Measures (Tobit)**

This table reports the Tobit estimates of how systemic risk measures are contemporaneously associated with crisis severity. The sample includes the all countries studied by Romer and Romer (2017) with the exception of Iceland from the second half of 2000 to the second half of 2012. The unit of observation is country-halfyear. The world SRISK variables are calculated using leave-one-out sums of respective SRISK variables. The country fixed effects are included in all specifications. Standard errors are reported in parentheses. ***, ** and * represent 1%, 5% and 10% significance, respectively.

	Dep Var: CRISIS			
	(1)	(2)	(3)	(4)
SRISK/(TA*k)	18.179***	12.997***	12.681***	15.398***
	(1.209)	(1.375)	(1.315)	(1.392)
D.SRISK/(TA*k)	6.822***		4.118**	
	(1.947)		(1.894)	
World SRISK/(TA*k)		14.300***		
		(2.413)		
D.World SRISK/(TA*k)		8.245***		
		(2.808)		
World SRISK/MV			9.921***	
			(1.551)	
World log SRISK				1.845***
				(0.364)
D.World log SRISK				4.095***
				(1.012)
var(e.CRISIS)	11.185***	9.964***	9.924***	10.716***
	(1.273)	(1.123)	(1.119)	(1.214)
Country FE	Yes	Yes	Yes	Yes
Pseudo R^2	0.260	0.290	0.285	0.281
Observations	561	561	561	561

Table 4: **Fixed Effects in Tobit Model**

This table reports the estimates of country fixed effects corresponding to models reported in Table 3. Standard errors are reported in parentheses. ***, ** and * represent 1%, 5% and 10% significance, respectively.

	Dep Var: CRISIS			
	(1)	(2)	(3)	(4)
Australia	-7.958***	-12.914***	-10.153***	-34.688***
	(1.410)	(1.670)	(1.461)	(5.470)
Austria	-7.216***	-10.489***	-7.920***	-32.759***
	(0.992)	(1.165)	(0.982)	(5.129)
Belgium	-15.779***	-17.930***	-15.257***	-40.947***
	(1.556)	(1.599)	(1.506)	(5.213)
Canada	-5.918***	-10.330***	-7.616***	-32.239***
	(1.012)	(1.309)	(1.062)	(5.295)
Denmark	-10.560***	-13.409***	-10.648***	-36.255***
	(1.236)	(1.345)	(1.192)	(5.188)
Finland	-6.321***	-11.022***	-8.582***	-32.725***
	(1.176)	(1.516)	(1.289)	(5.416)
France	-11.701***	-13.419***	-10.706***	-36.629***
	(1.173)	(1.216)	(1.116)	(5.016)
Germany	-11.594***	-13.358***	-10.632***	-36.512***
	(1.133)	(1.180)	(1.083)	(4.987)
Greece	-5.139***	-8.425***	-5.979***	-30.818***
	(1.111)	(1.243)	(1.053)	(5.225)
Ireland	-7.710***	-10.476***	-7.771***	-33.365***
	(1.118)	(1.215)	(1.059)	(5.139)
Italy	-5.677***	-8.991***	-6.388***	-31.426***
	(1.001)	(1.171)	(0.968)	(5.172)
Japan	-8.628***	-10.149***	-7.693***	-32.899***
	(1.013)	(1.020)	(0.950)	(4.833)
Luxembourg	-9.862***	-13.349***	-10.710***	-35.865***
	(1.301)	(1.428)	(1.258)	(5.295)
Netherlands	-14.523***	-16.510***	-13.766***	-39.629***
	(1.378)	(1.432)	(1.322)	(5.133)
New Zealand	0.369	-5.410***	-2.693***	-27.144***
	(0.944)	(1.329)	(1.037)	(5.439)
Norway	-8.247***	-11.782***	-9.134***	-34.270***
	(1.176)	(1.338)	(1.148)	(5.273)
Portugal	-3.907***	-7.422***	-4.916***	-29.756***
	(0.992)	(1.180)	(0.963)	(5.212)
Spain	-3.802***	-7.696***	-5.164***	-29.826***
	(0.939)	(1.184)	(0.946)	(5.233)
Sweden	-9.199***	-12.536***	-9.812***	-35.049***
	(1.135)	(1.310)	(1.126)	(5.213)
Switzerland	-10.762***	-14.024***	-11.251***	-36.613***
	(1.201)	(1.364)	(1.189)	(5.224)
Turkey	-0.849	-5.527***	-3.073***	-27.107***
	(0.794)	(1.120)	(0.854)	(5.203)
United Kingdom	-6.587***	-9.534***	-6.831***	-32.147***
	(1.040)	(1.160)	(0.984)	(5.114)
United States	-4.591***	-8.374***	-5.747***	-30.086***
	(0.895)	(1.112)	(0.896)	(5.063)
Pseudo R^2	0.260	0.290	0.285	0.281
Observations	561	561	561	561

Appendix: Measures for Other Countries

This appendix contains the the *Probability of Crisis* and the *SRISK Capacity* measures for all 23 countries that are studied by Romer and Romer (2017) and have SRISK data.

List of Figures

Figure A.1: **Probability of Crisis (%) - Australia**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

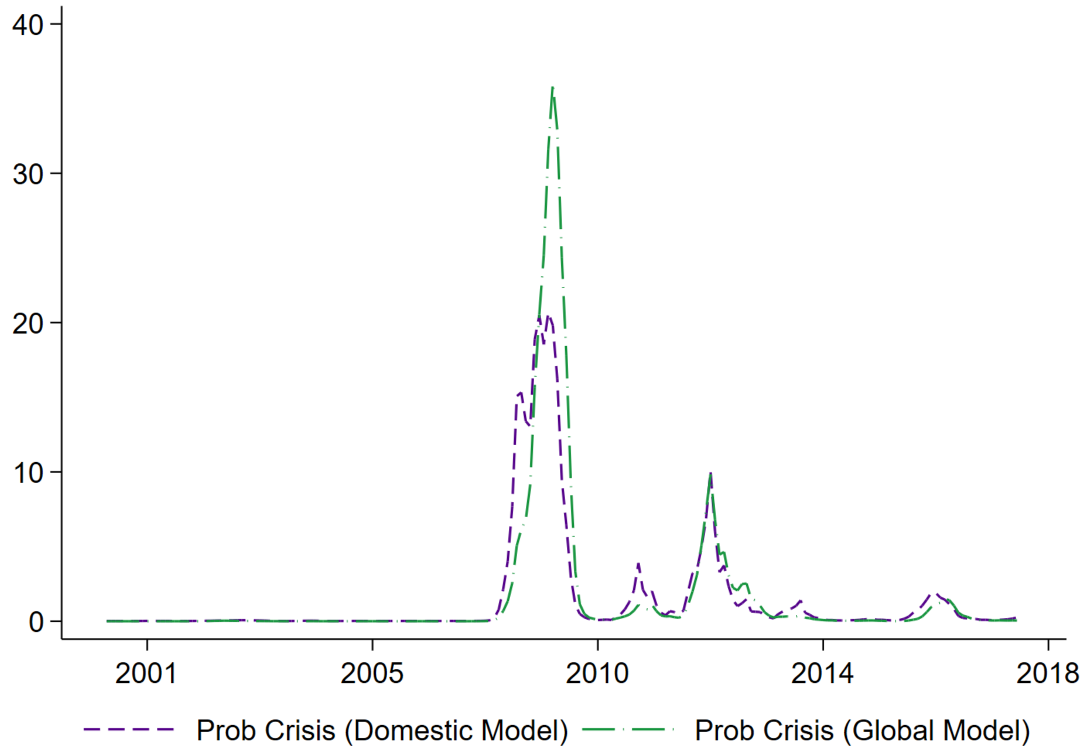

Figure A.2: **SRISK Capacity (USD Million) - Australia**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

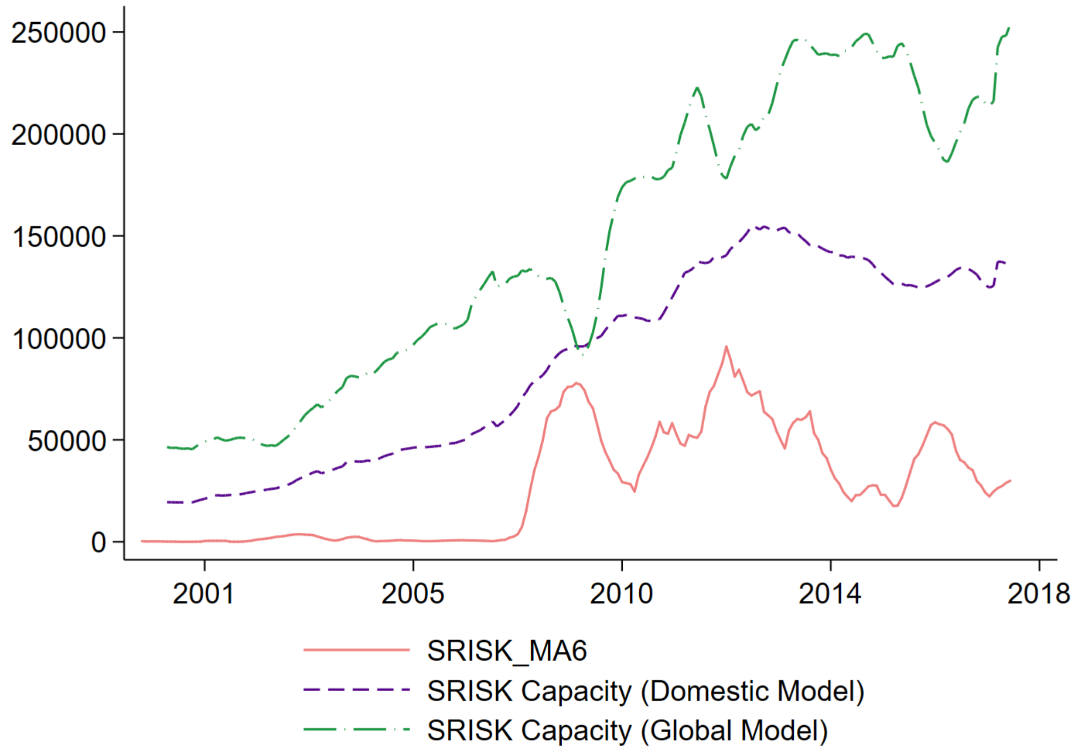

Figure A.3: **Probability of Crisis (%) - Austria**

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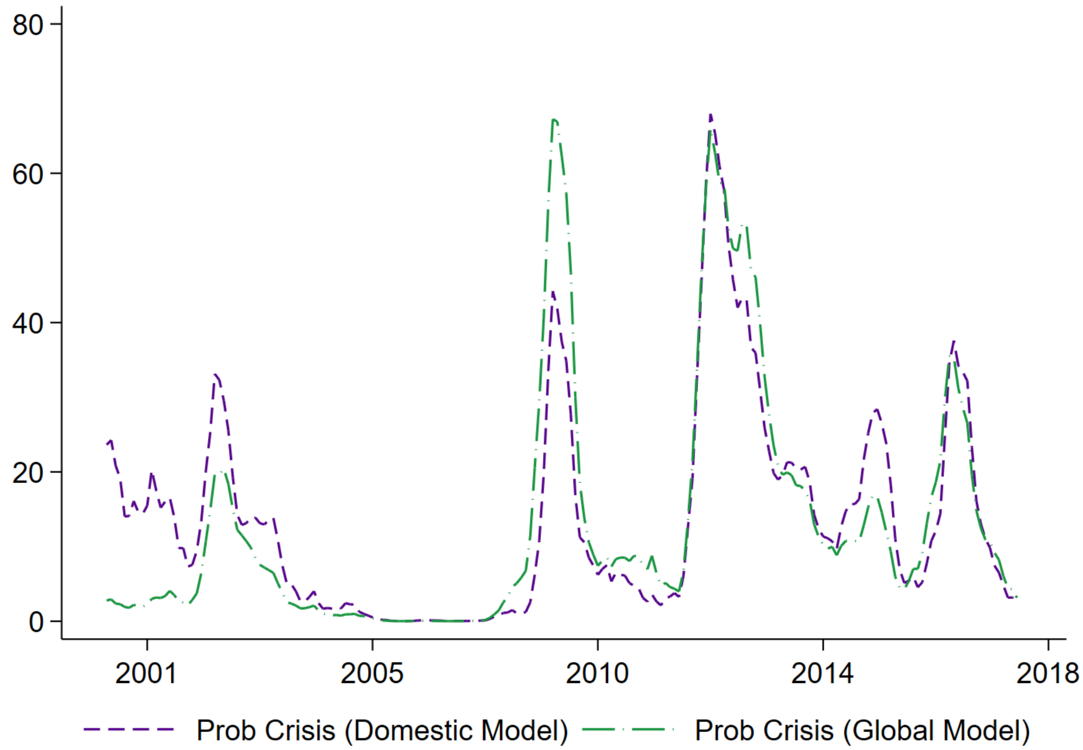

Figure A.4: **SRISK Capacity (USD Million) - Austria**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

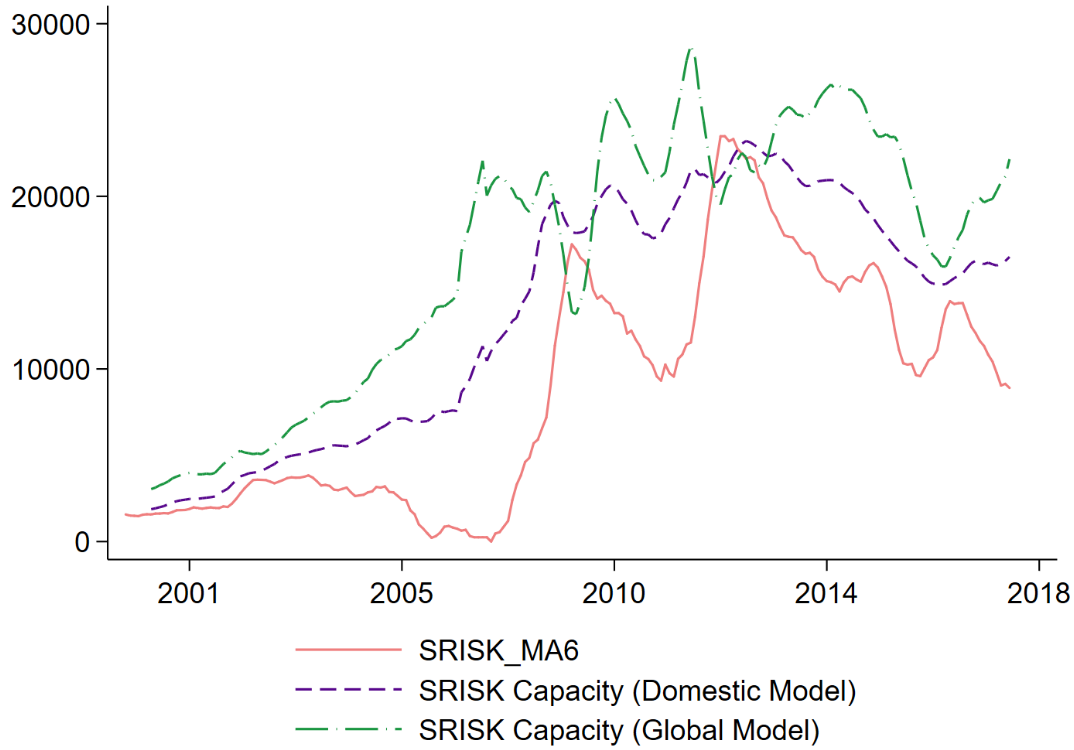

Figure A.5: **Probability of Crisis (%) - Belgium**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

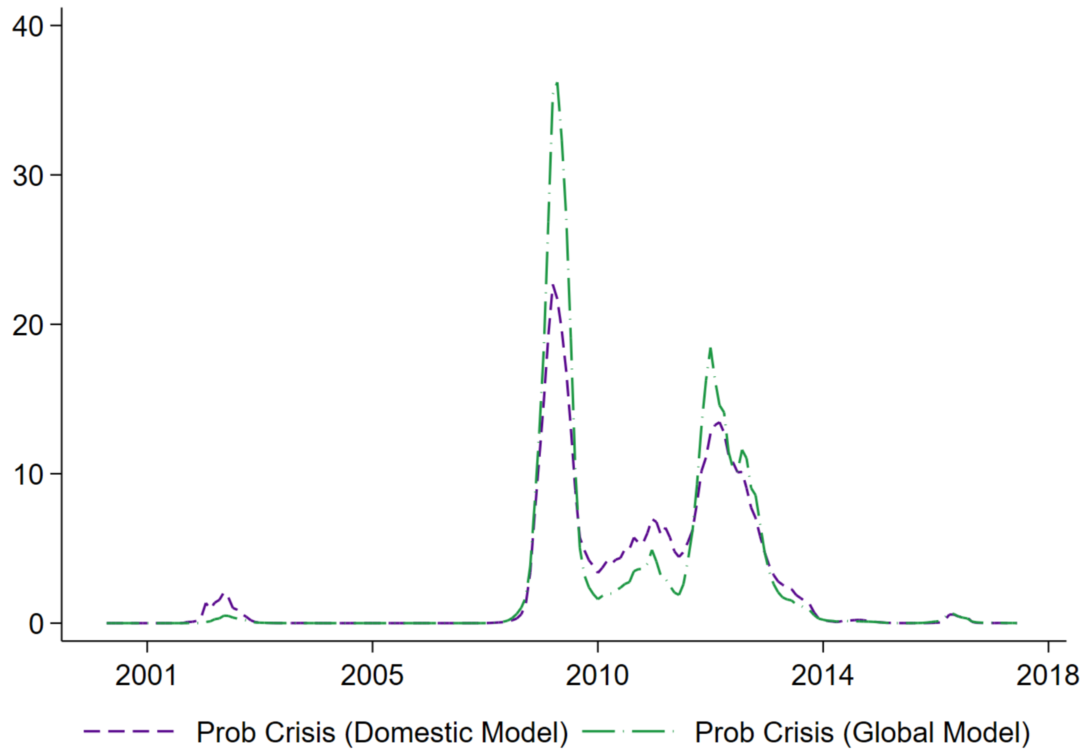

Figure A.6: **SRISK Capacity (USD Million) - Belgium**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

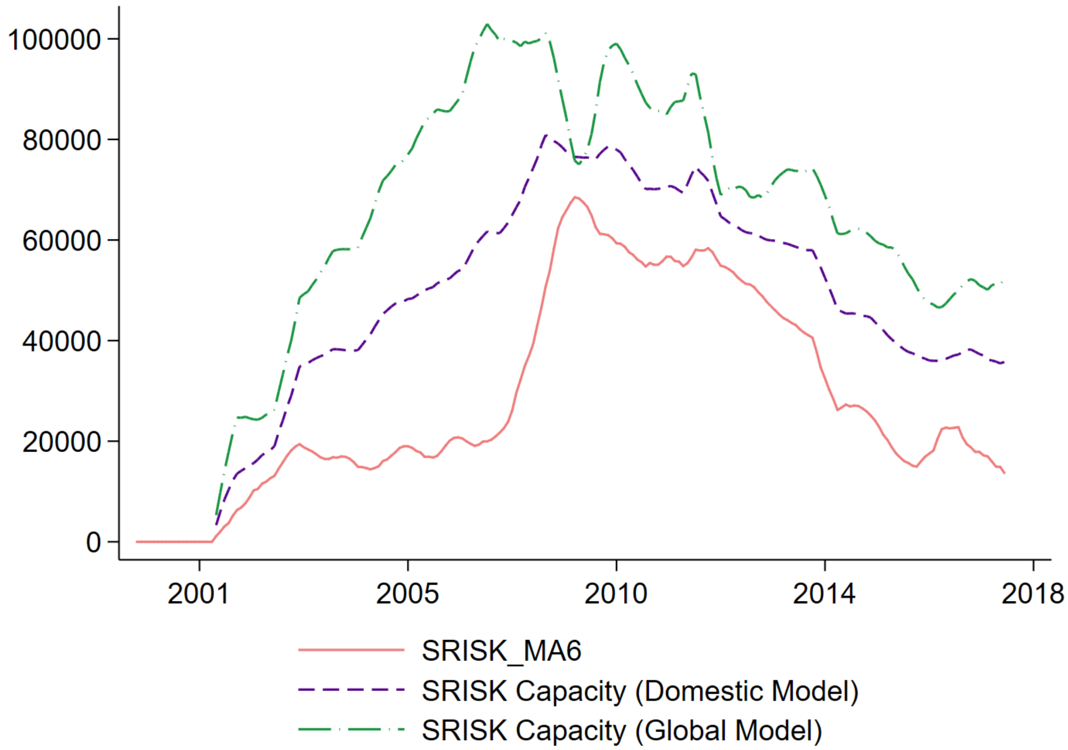

Figure A.7: **Probability of Crisis (%) - Canada**

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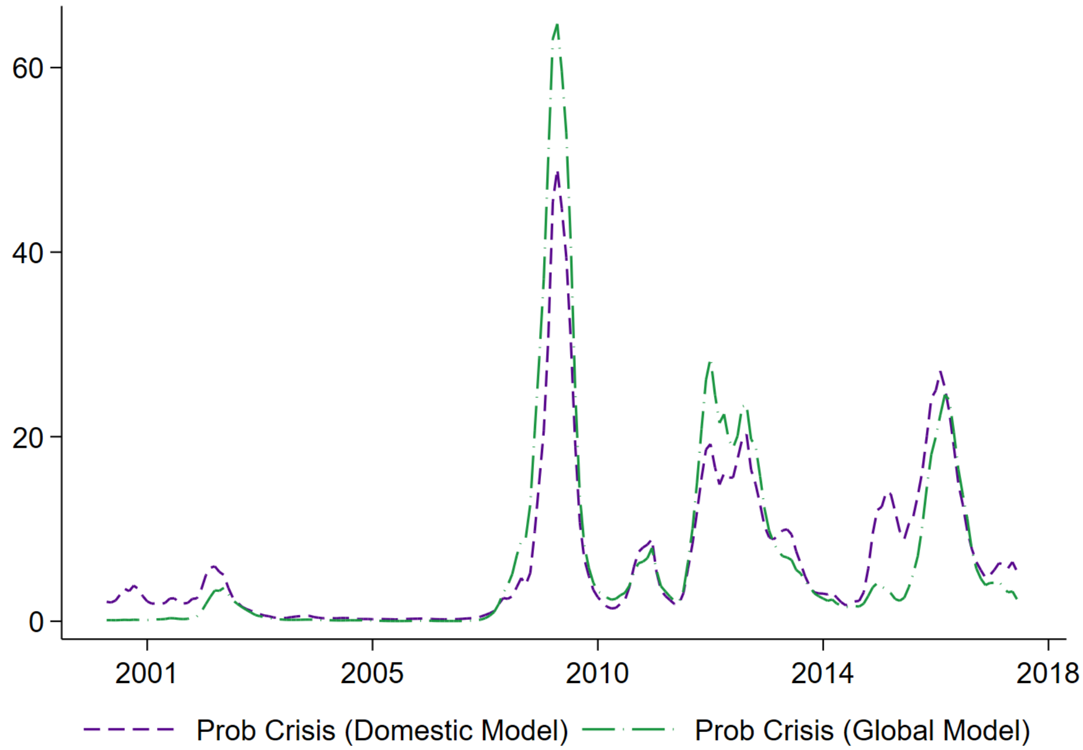

Figure A.8: **SRISK Capacity (USD Million) - Canada**

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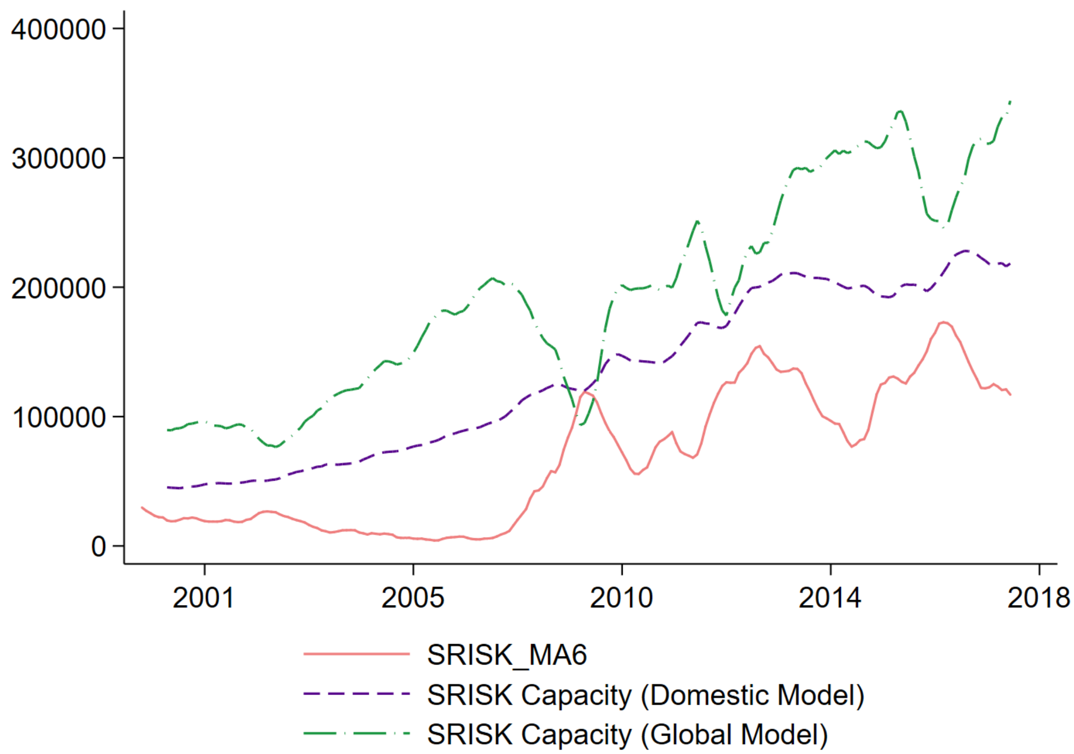

Figure A.9: **Probability of Crisis (%) - Denmark**

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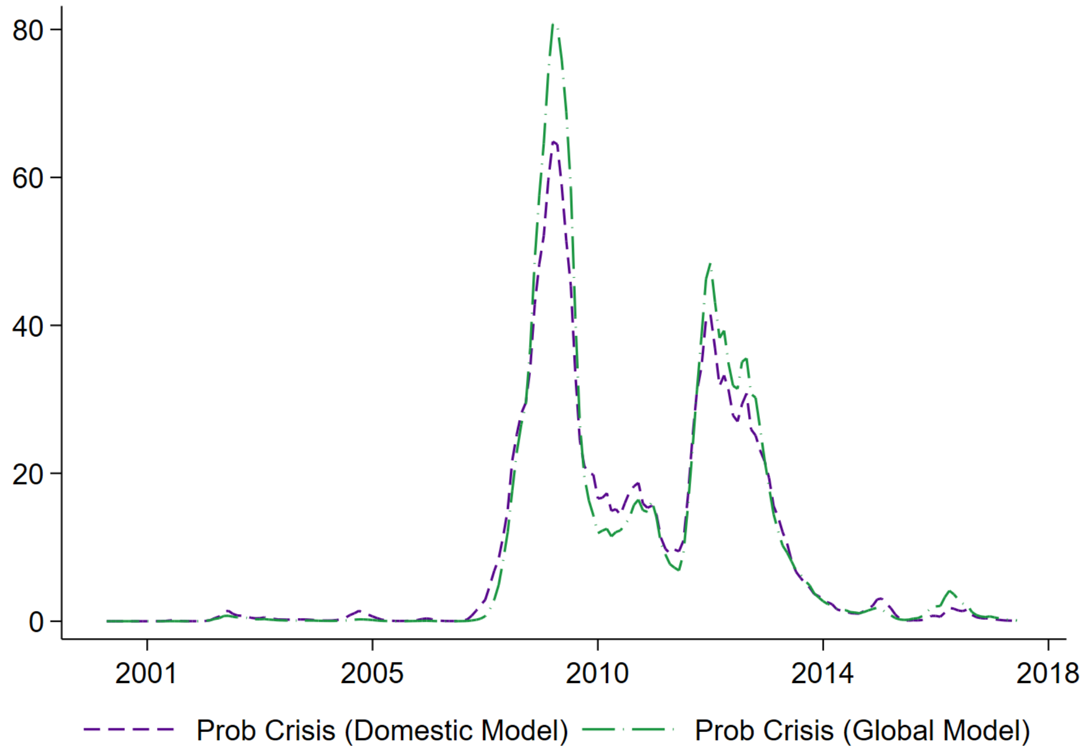

Figure A.10: **SRISK Capacity (USD Million) - Denmark**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

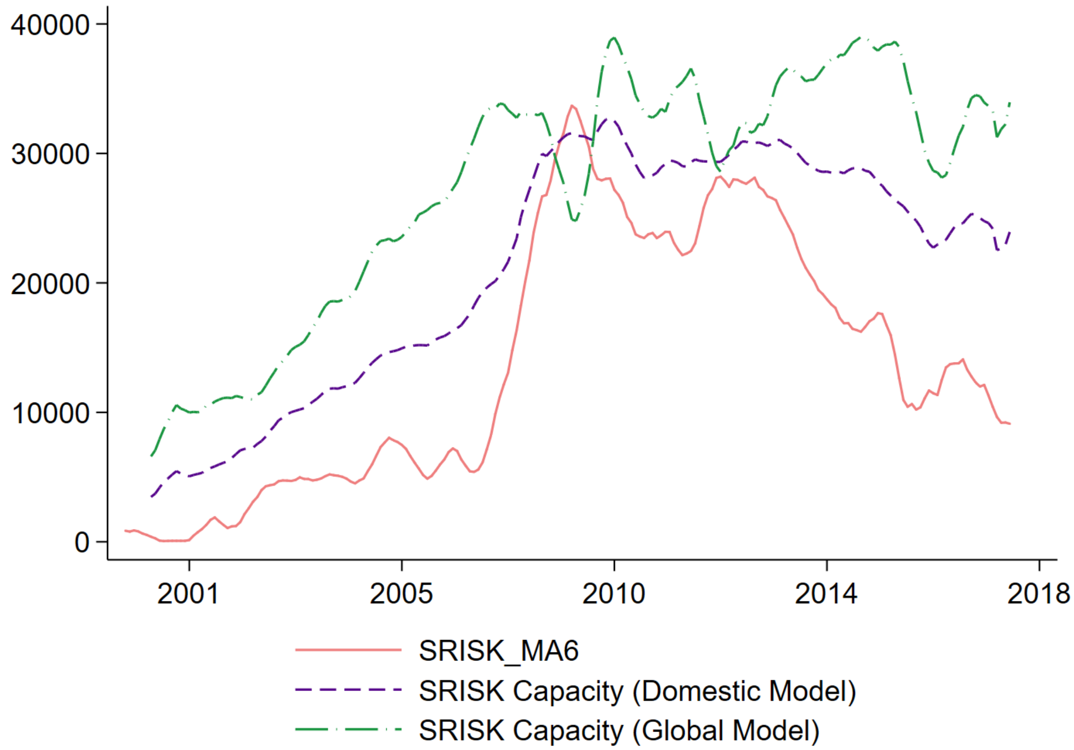

Figure A.11: **Probability of Crisis (%) - Finland**

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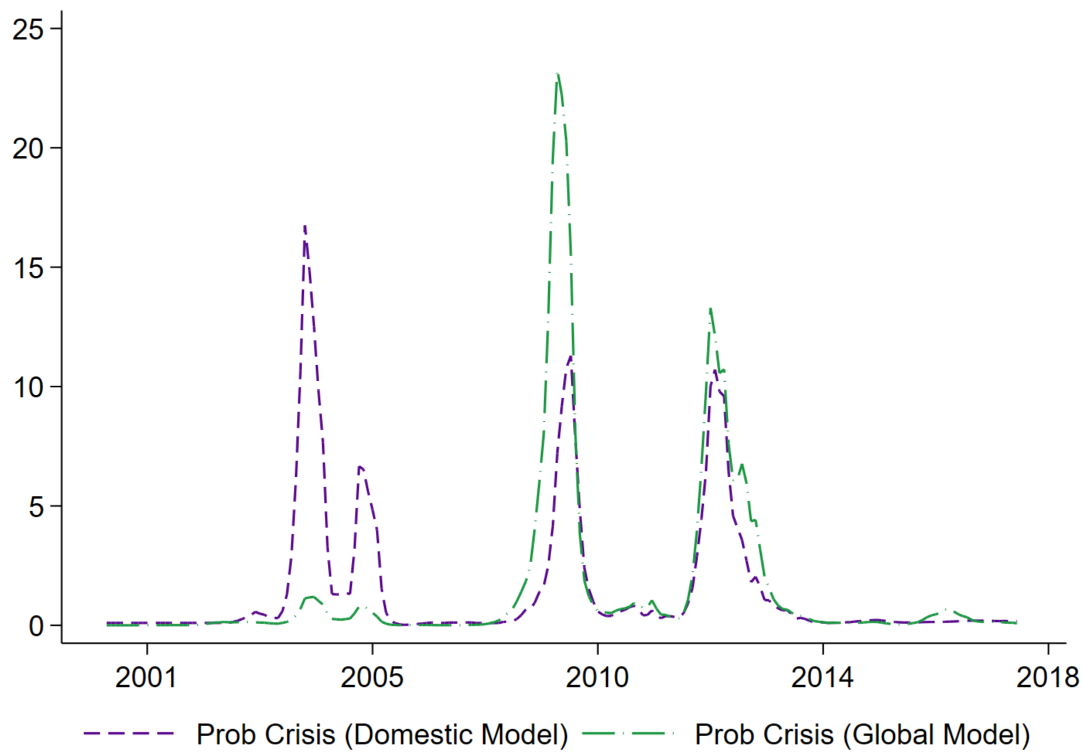

Figure A.12: **SRISK Capacity (USD Million) - Finland**

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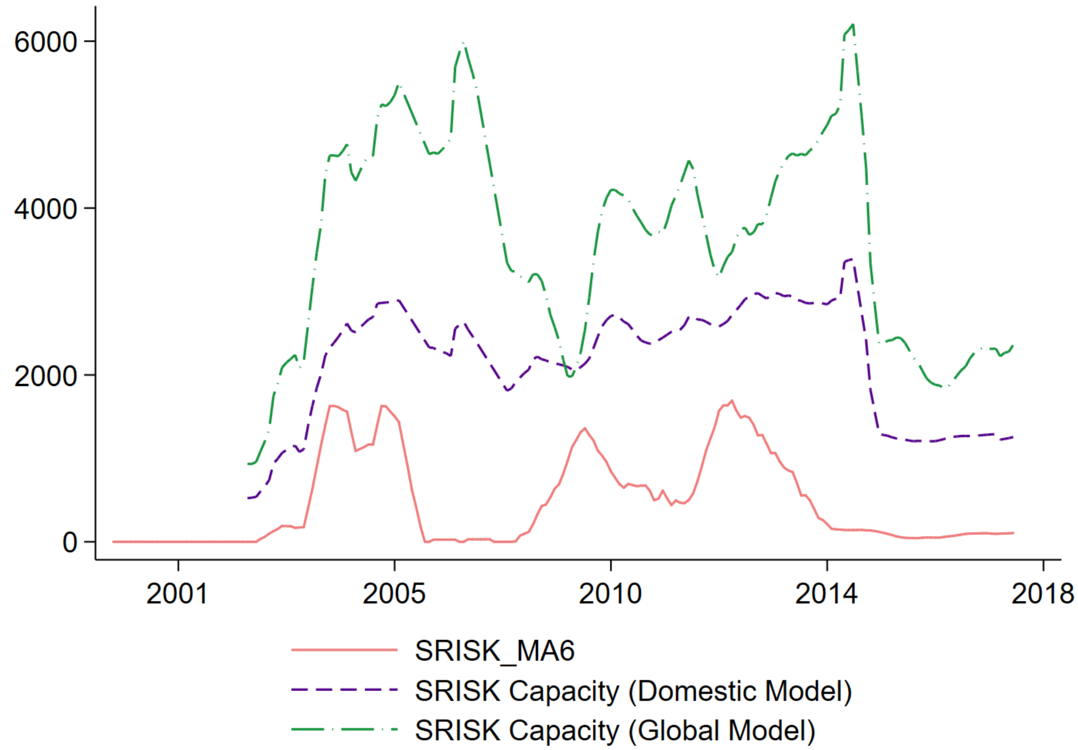

Figure A.13: **Probability of Crisis (%) - France**

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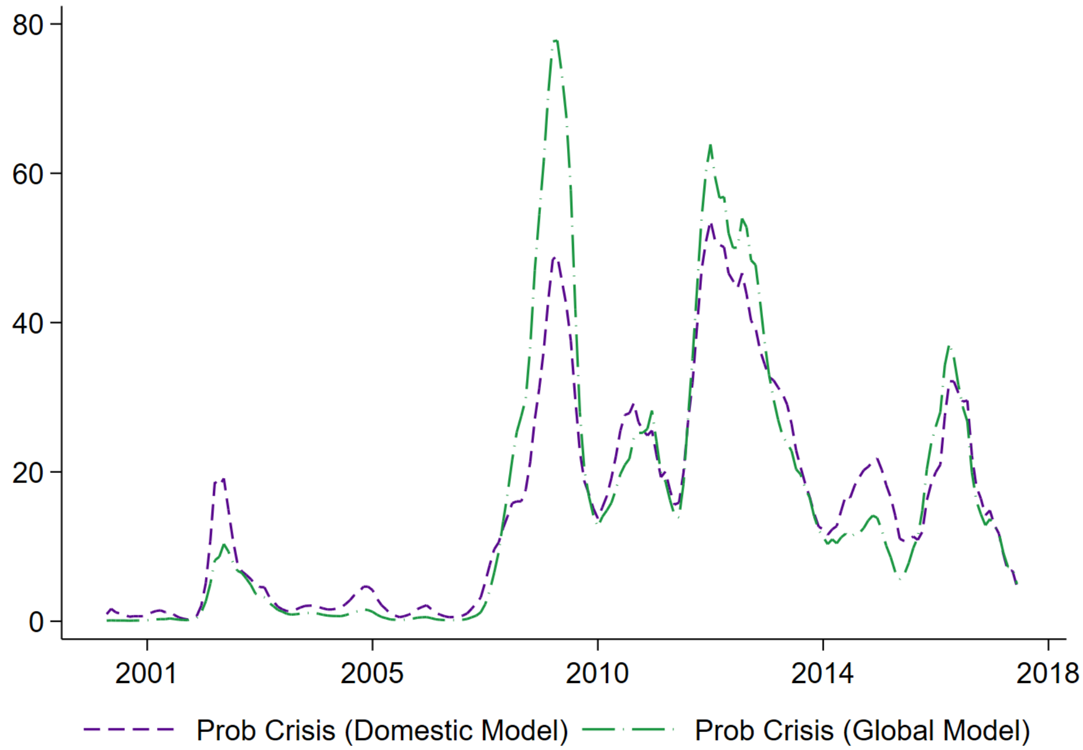

Figure A.14: **SRISK Capacity (USD Million) - France**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

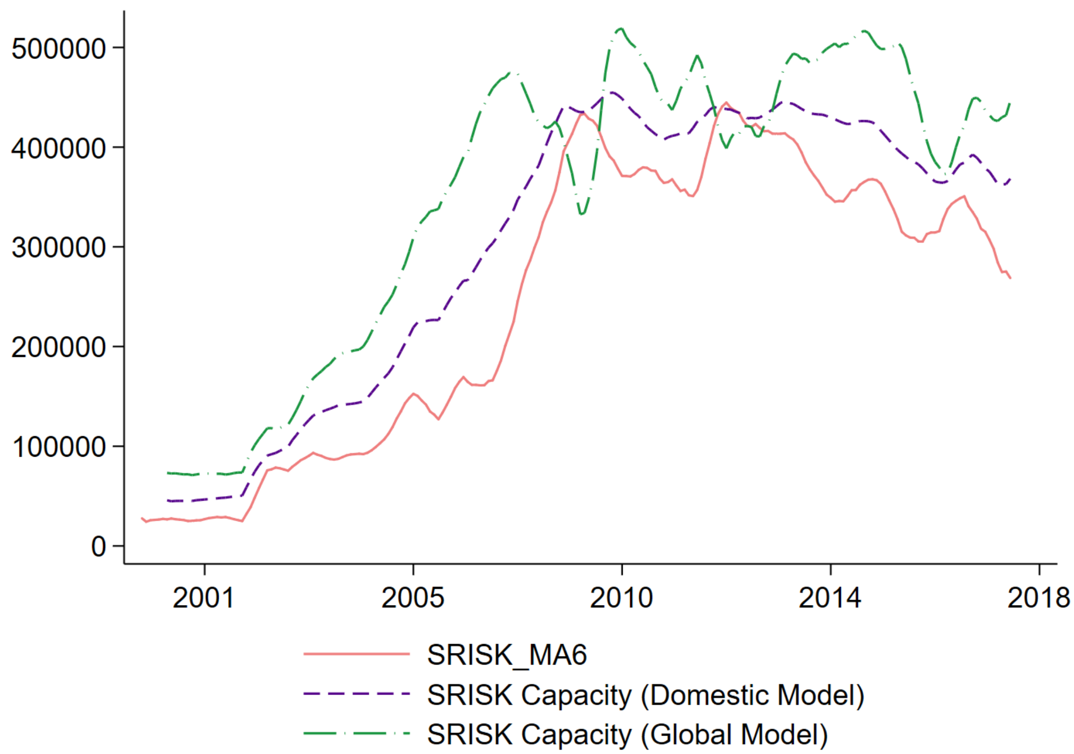

Figure A.15: **Probability of Crisis (%) - Germany**

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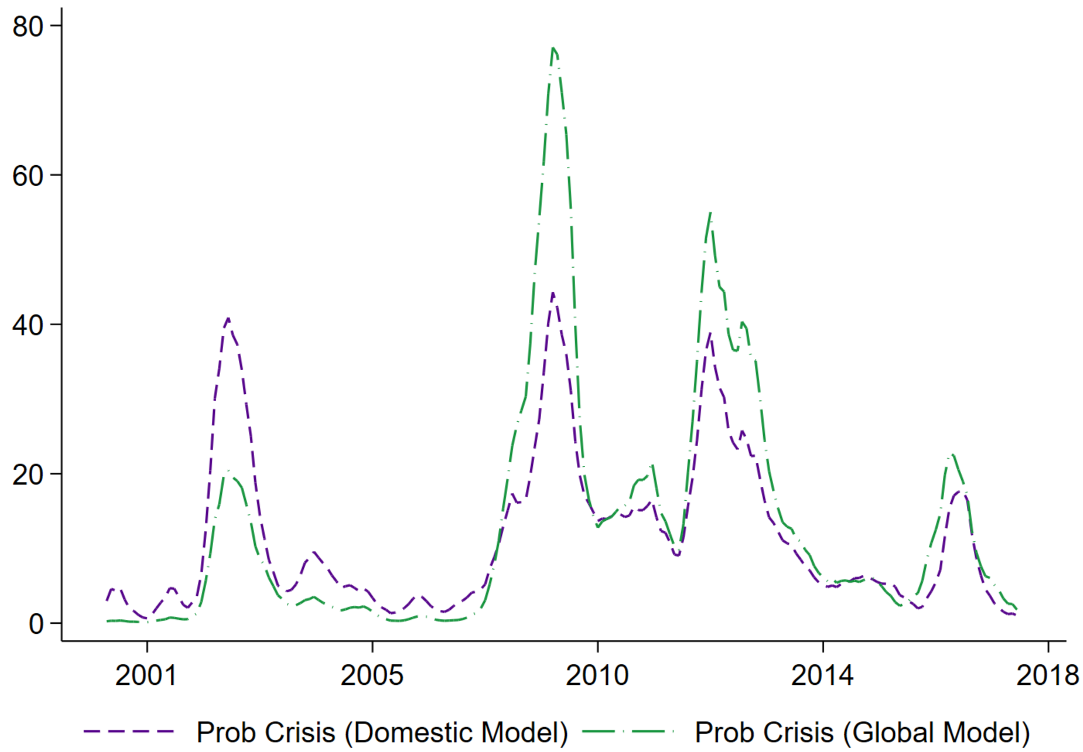

Figure A.16: **SRISK Capacity (USD Million) - Germany**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

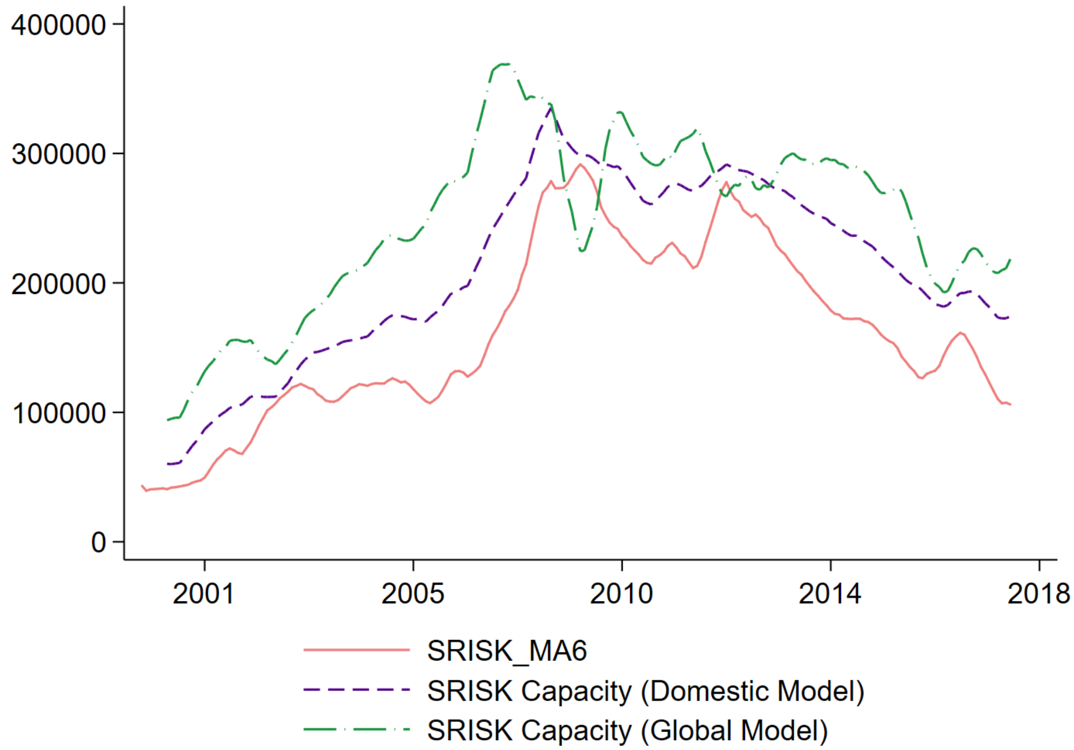

Figure A.17: **Probability of Crisis (%) - Greece**

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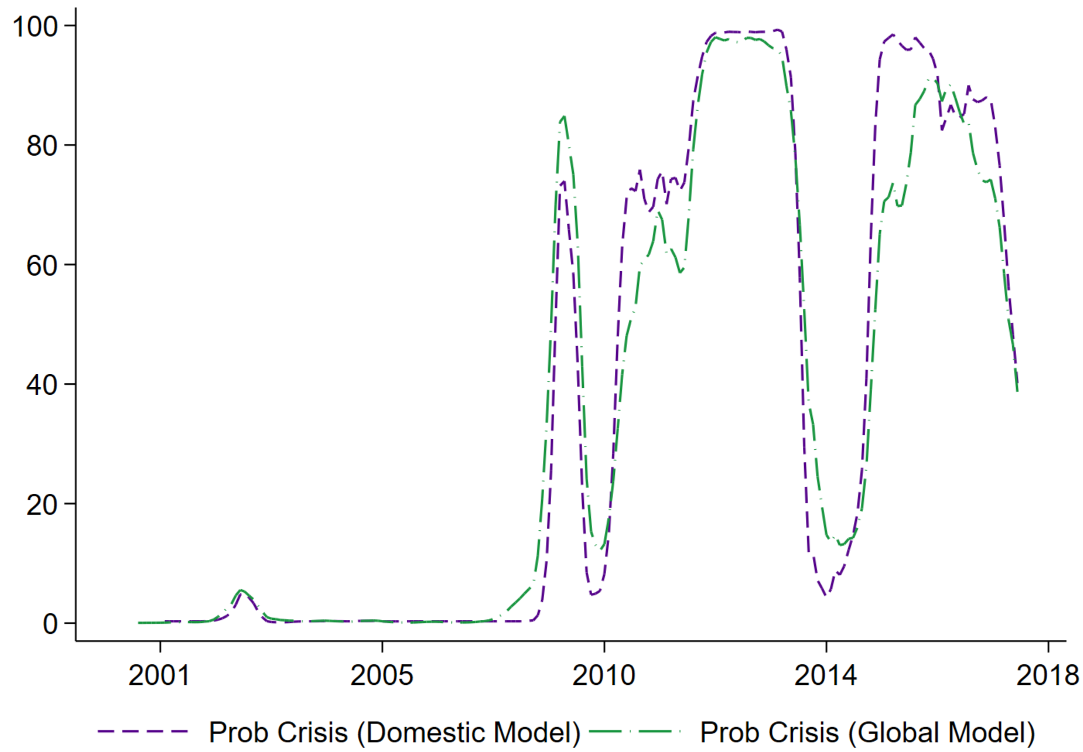

Figure A.18: **SRISK Capacity (USD Million) - Greece**

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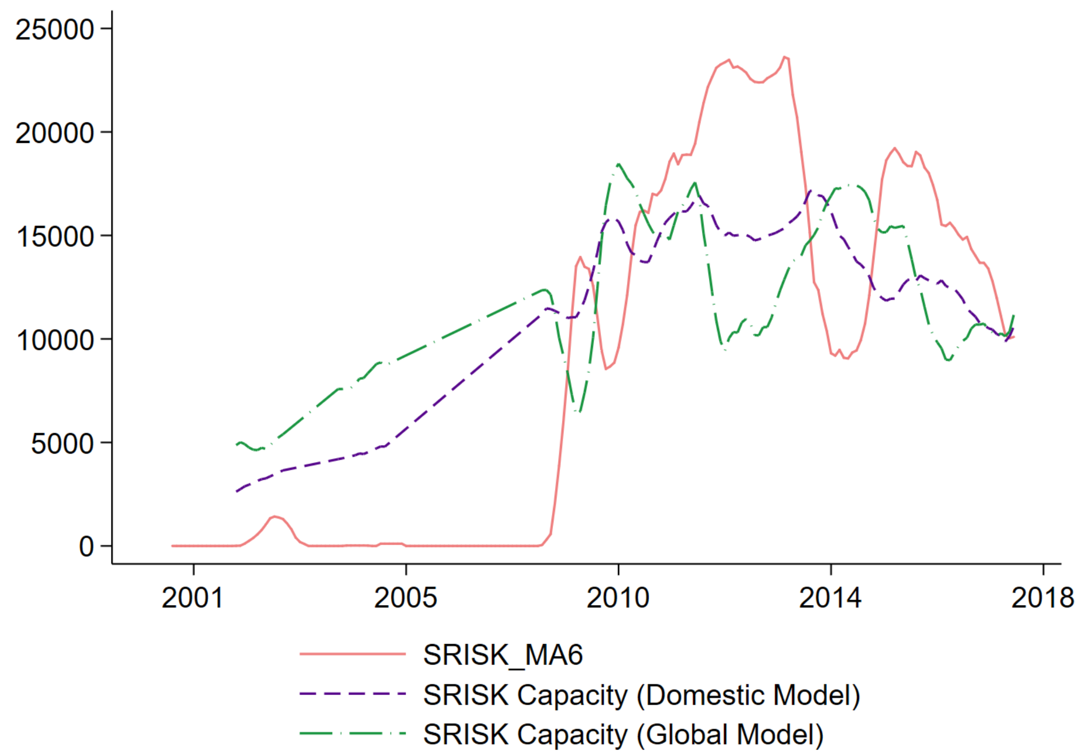

Figure A.19: **Probability of Crisis (%) - Ireland**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

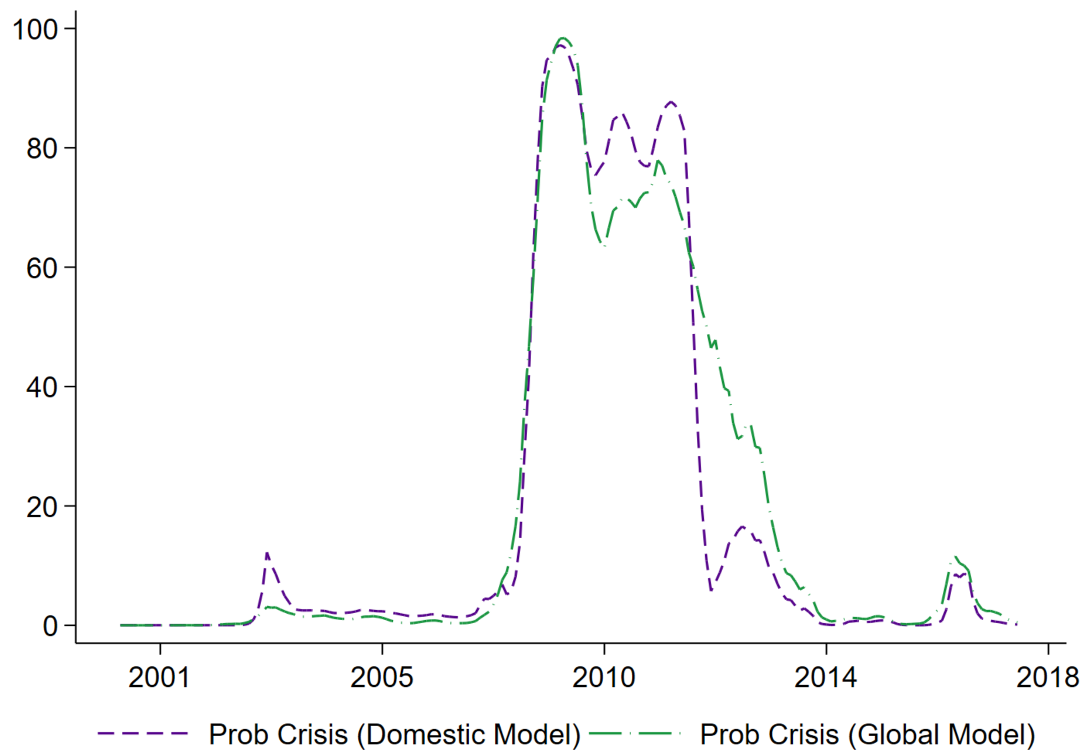

Figure A.20: **SRISK Capacity (USD Million) - Ireland**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

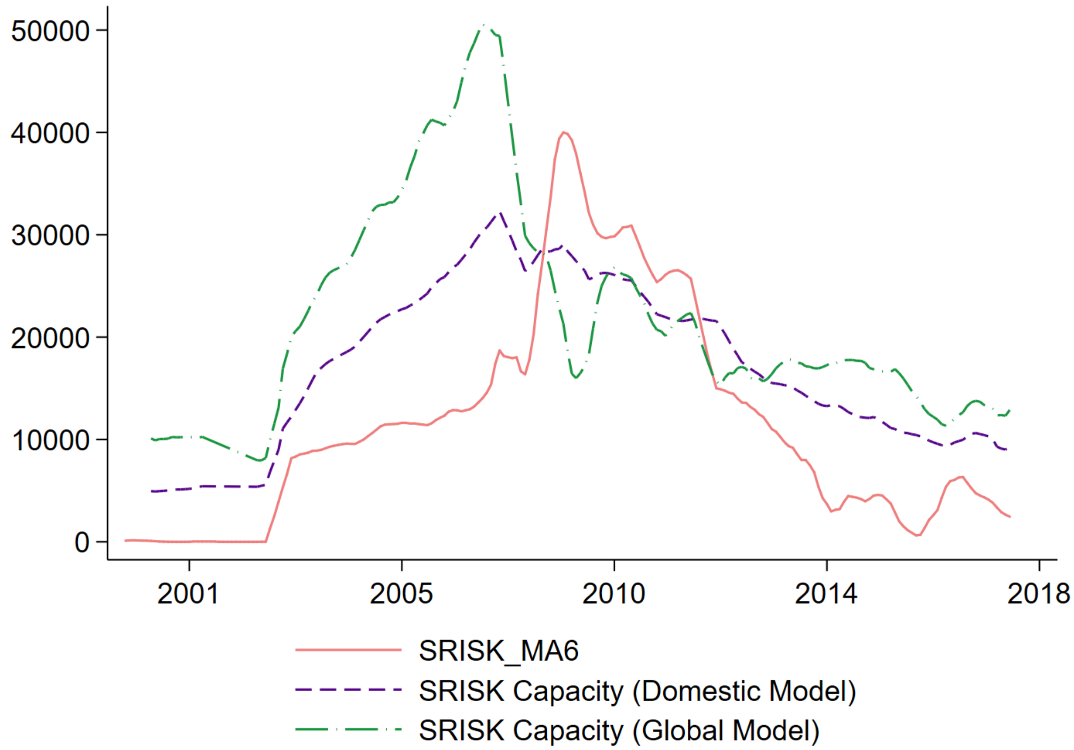

Figure A.21: **Probability of Crisis (%) - Italy**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

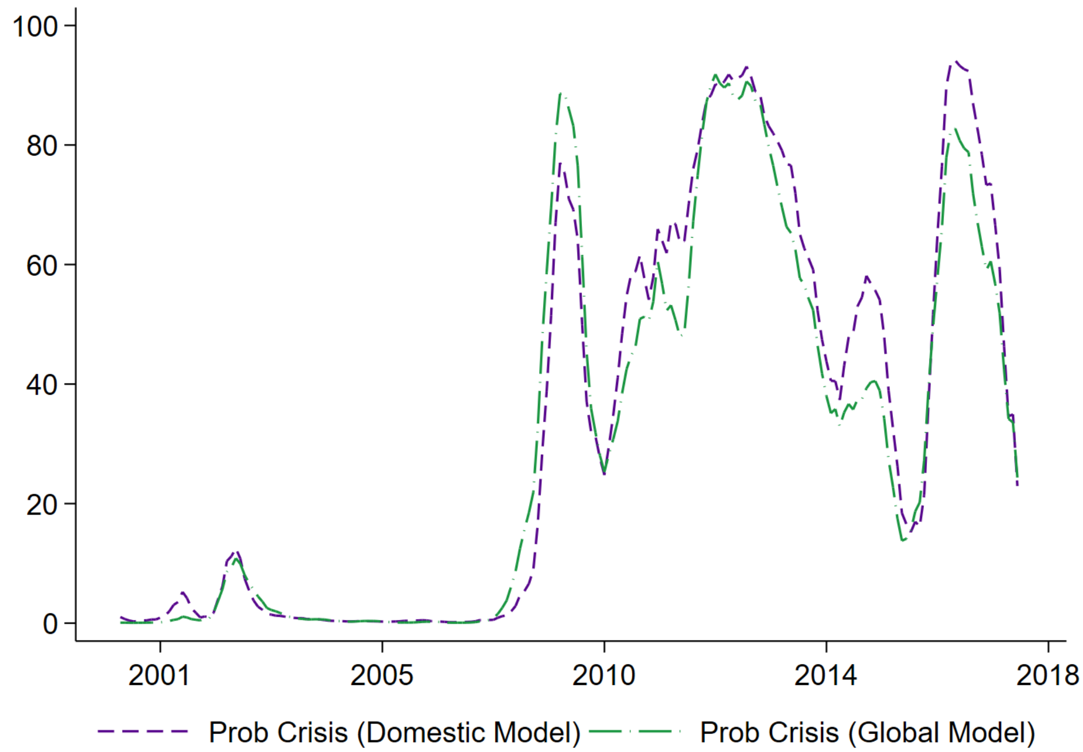

Figure A.22: **SRISK Capacity (USD Million) - Italy**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

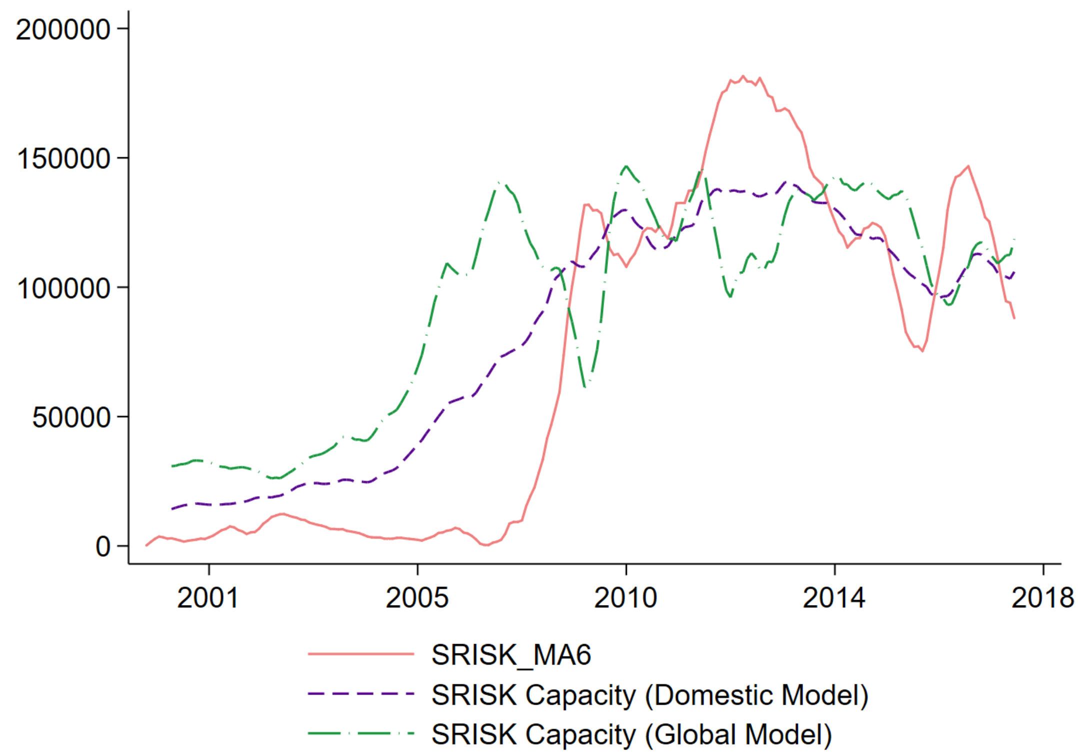

Figure A.23: **Probability of Crisis (%) - Japan**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

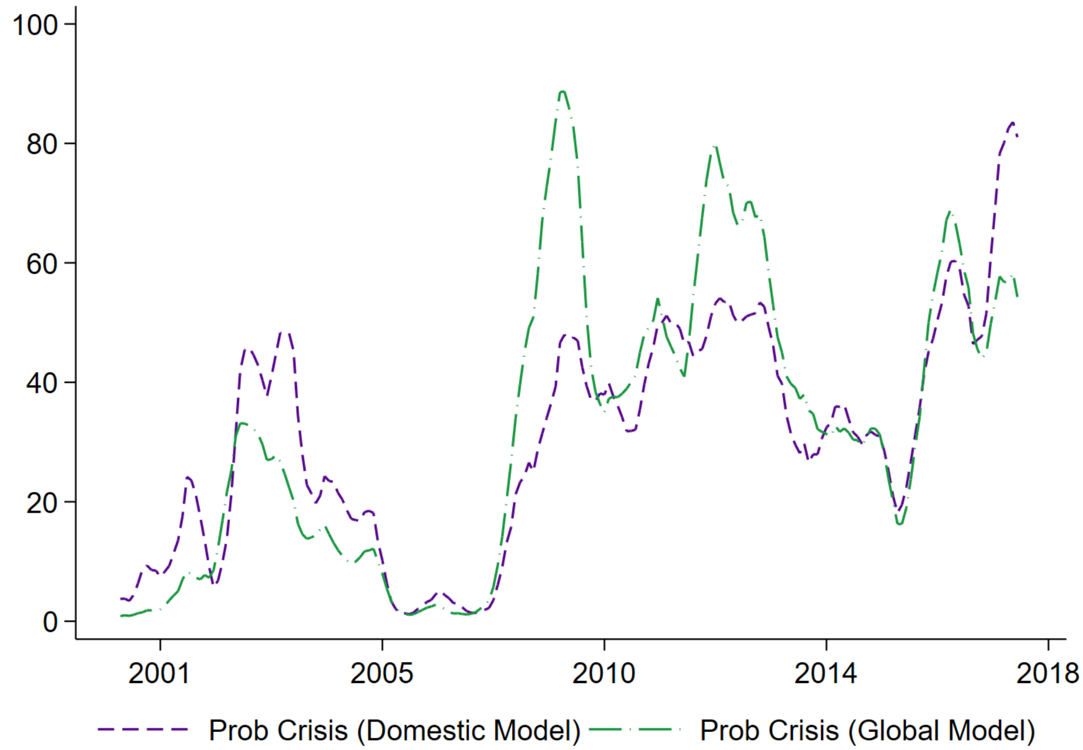

Figure A.24: **SRISK Capacity (USD Million) - Japan**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

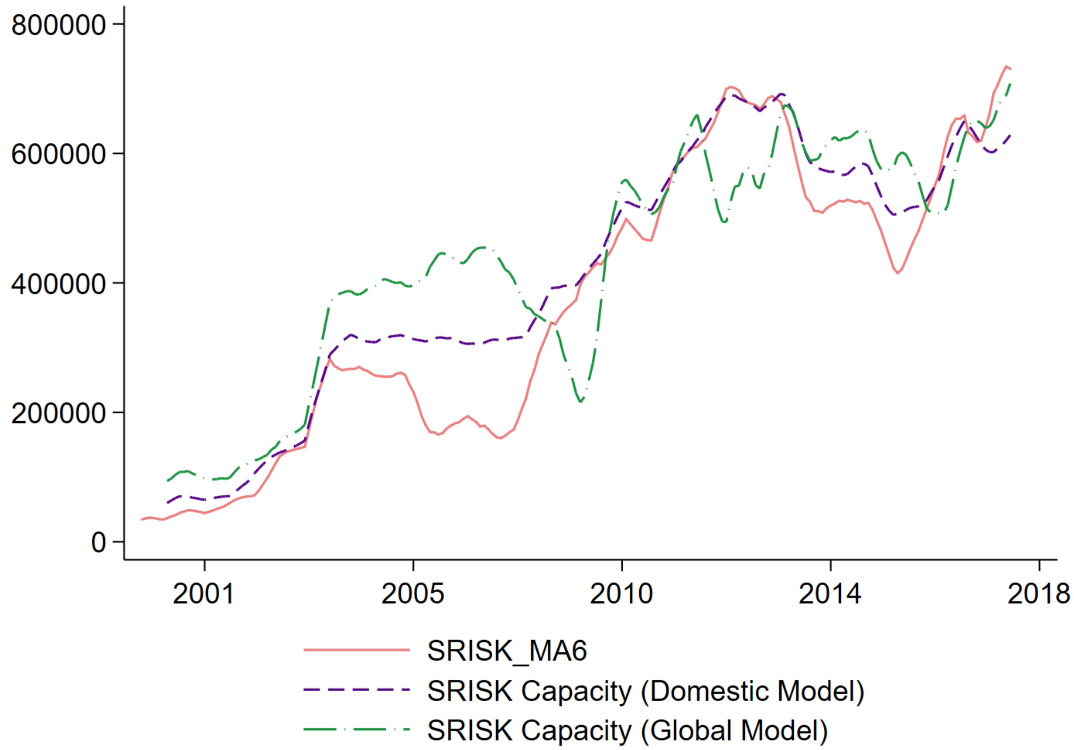

Figure A.25: **Probability of Crisis (%) - Luxembourg**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

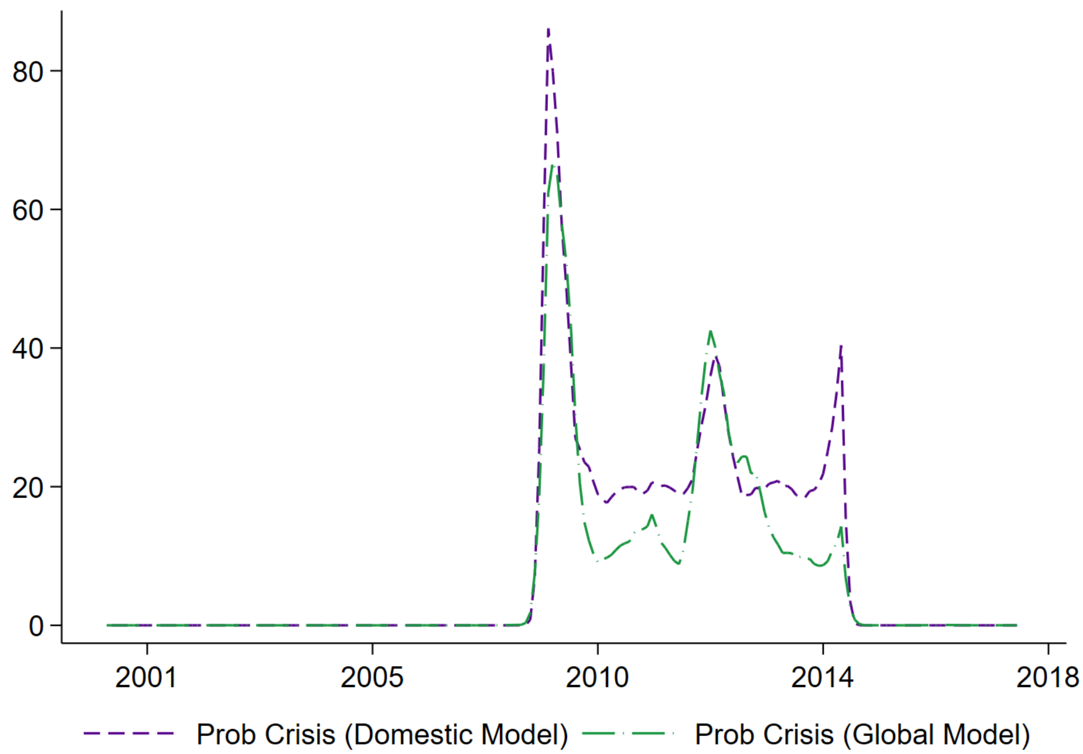

Figure A.26: **SRISK Capacity (USD Million) - Luxembourg**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

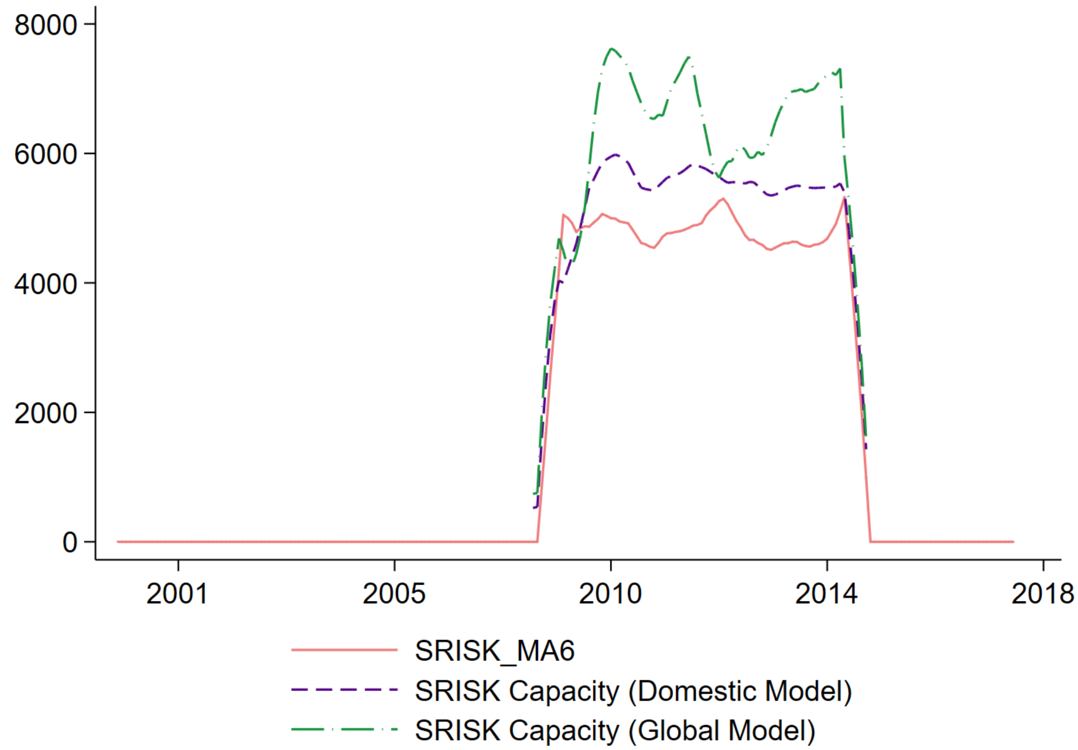

Figure A.27: **Probability of Crisis (%) - Netherlands**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

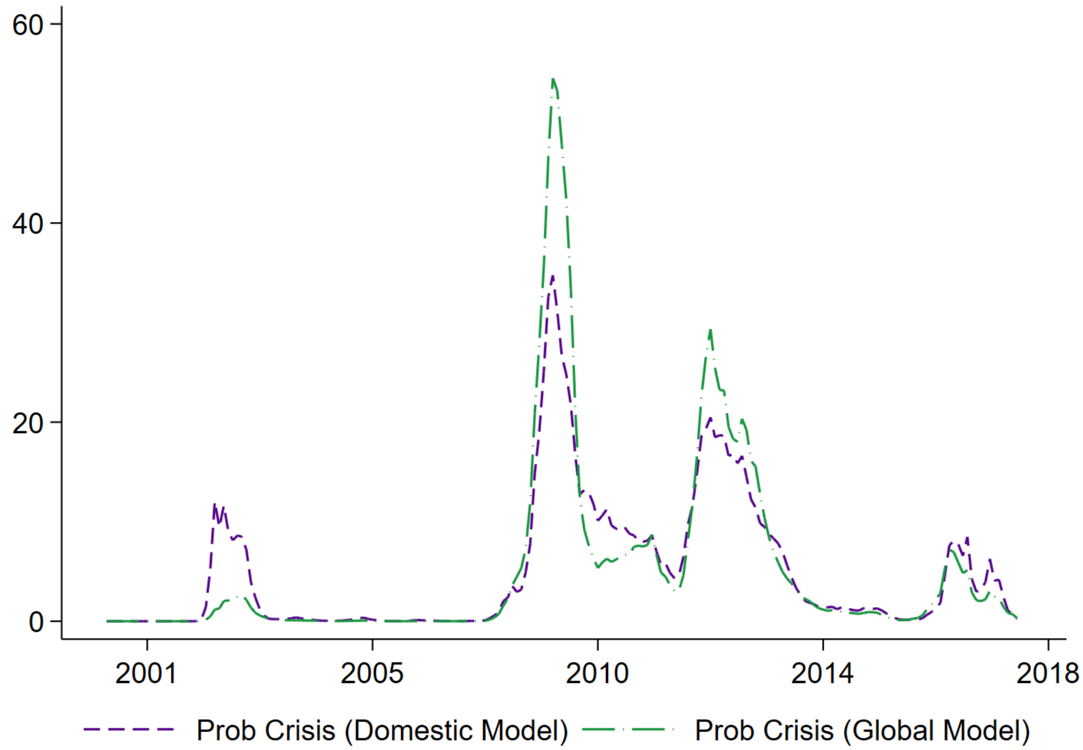

Figure A.28: **SRISK Capacity (USD Million) - Netherlands**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

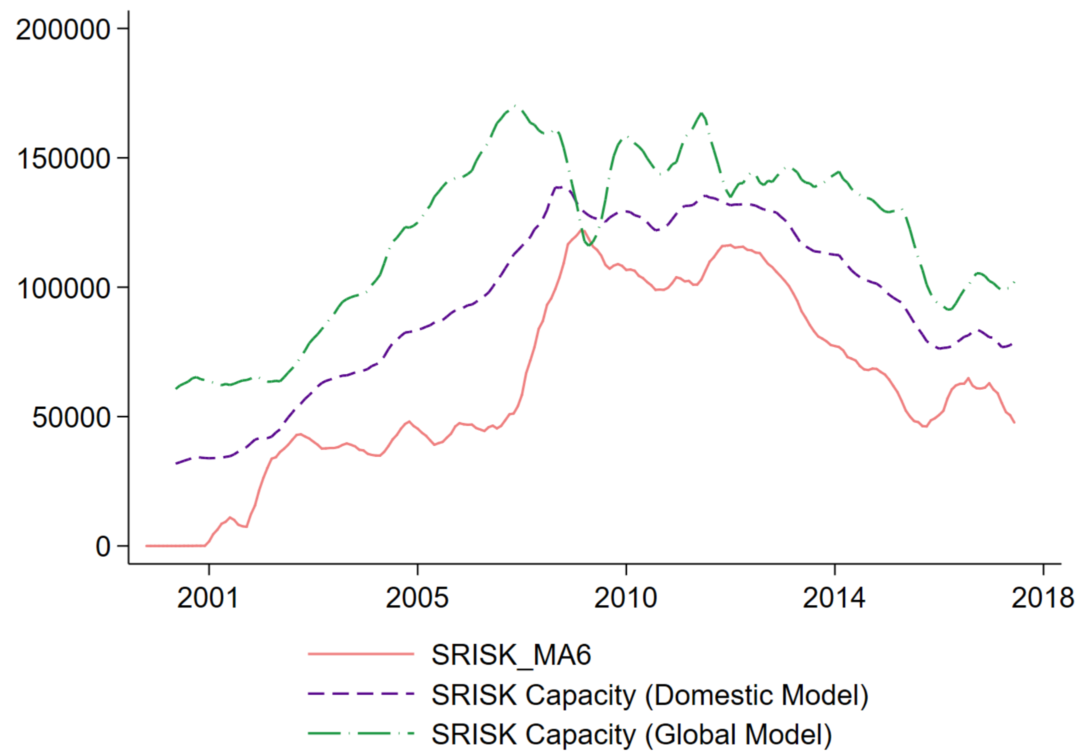

Figure A.29: **Probability of Crisis (%) - New Zealand**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

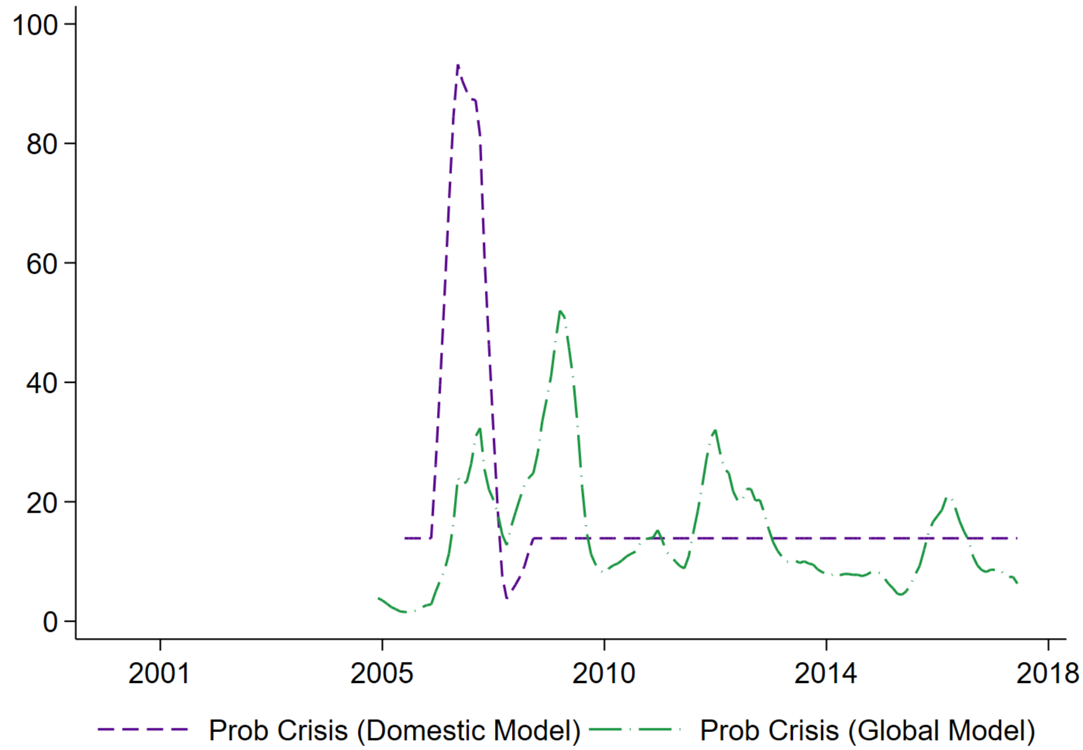

Figure A.30: **SRISK Capacity (USD Million) - New Zealand**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

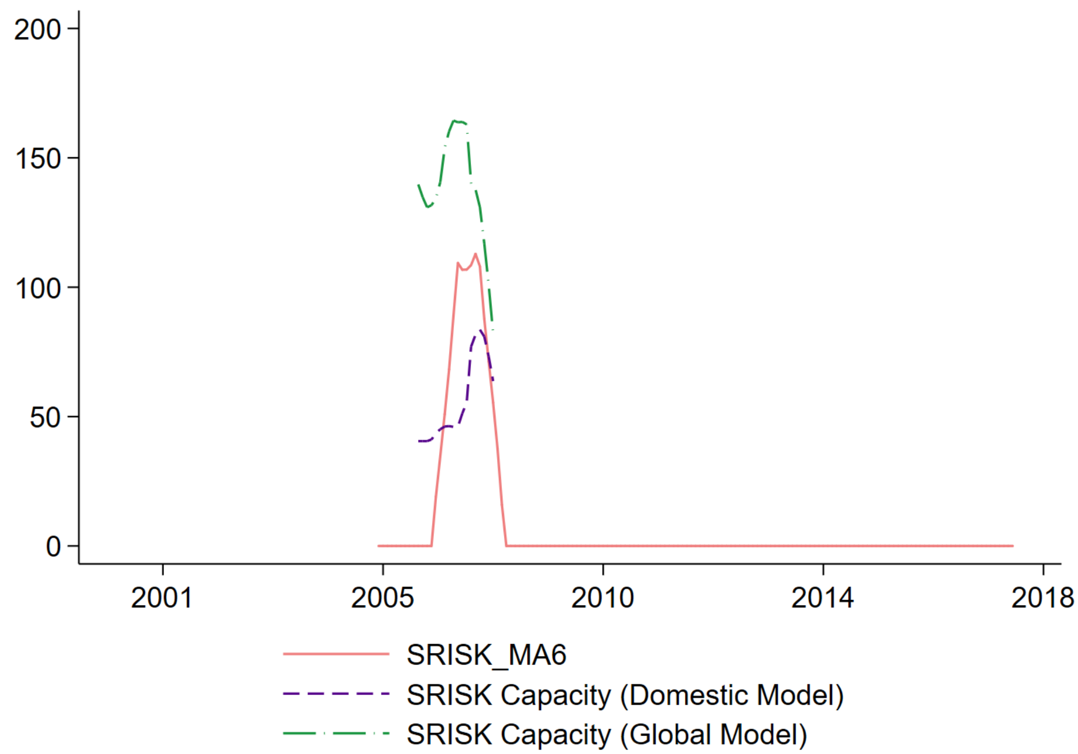

Figure A.31: **Probability of Crisis (%) - Norway**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

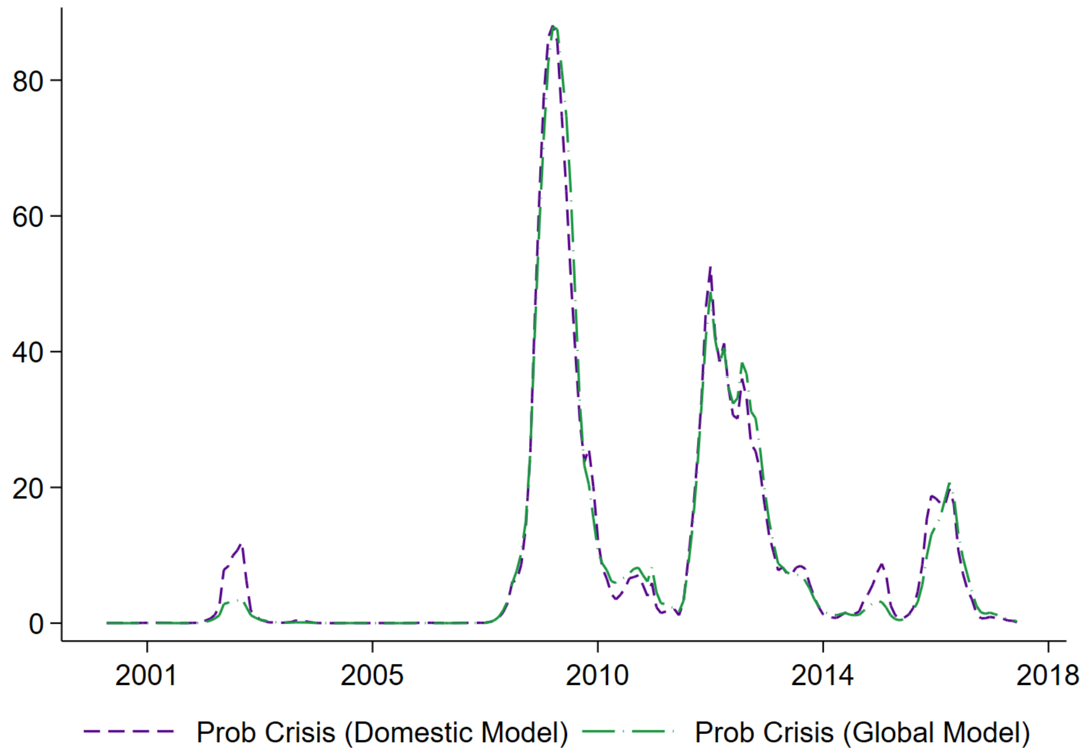

Figure A.32: **SRISK Capacity (USD Million) - Norway**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

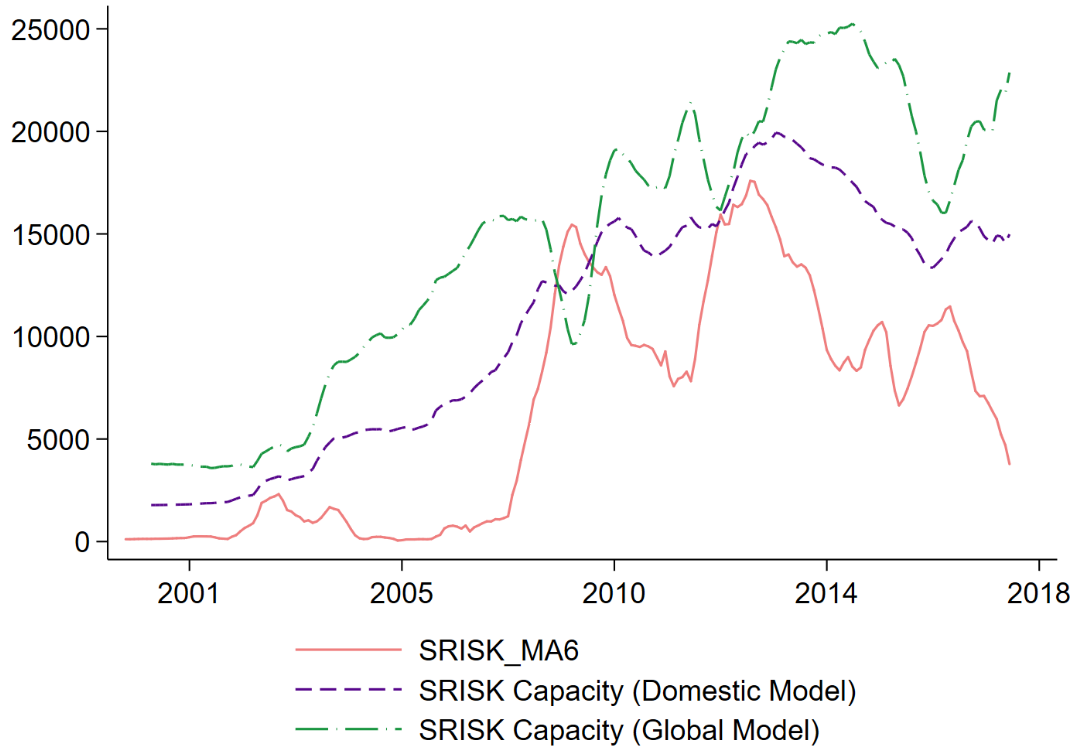

Figure A.33: **Probability of Crisis (%) - Portugal**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

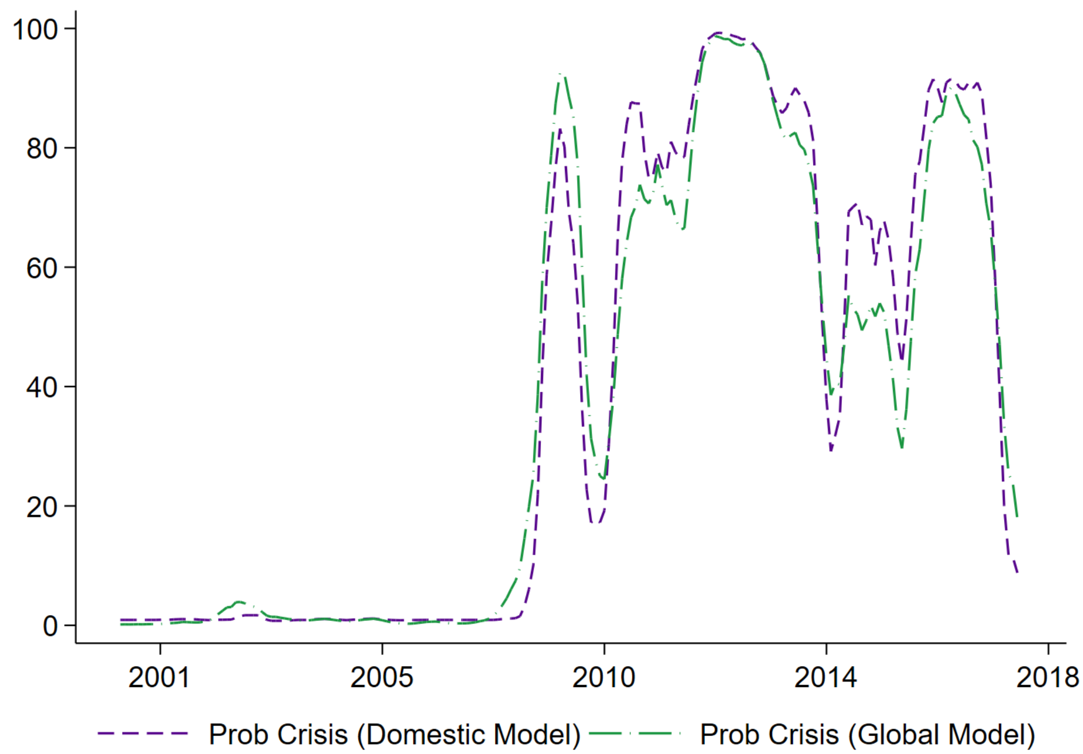

Figure A.34: **SRISK Capacity (USD Million) - Portugal**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

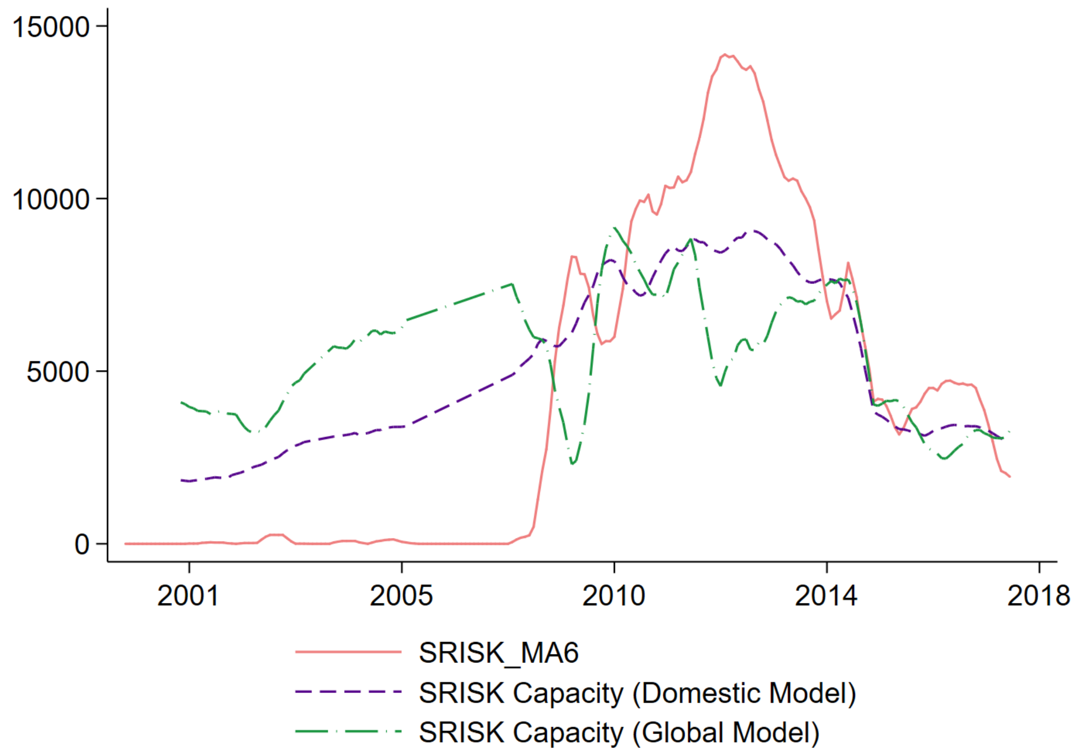

Figure A.35: **Probability of Crisis (%) - Spain**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

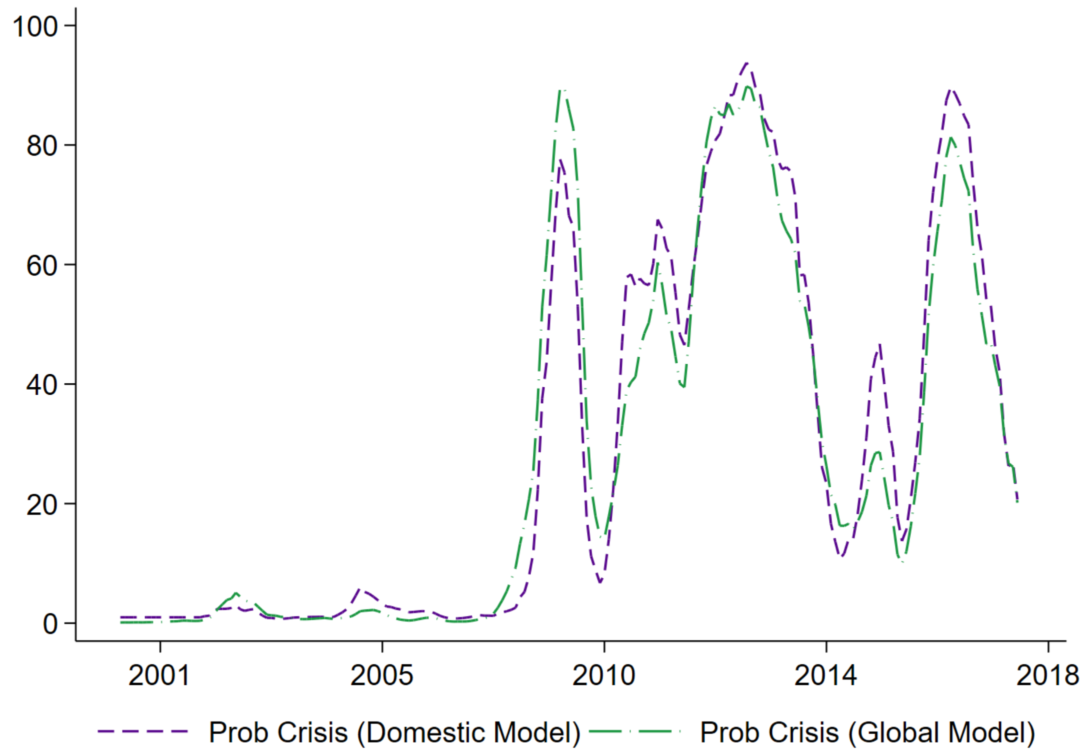

Figure A.36: **SRISK Capacity (USD Million) - Spain**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

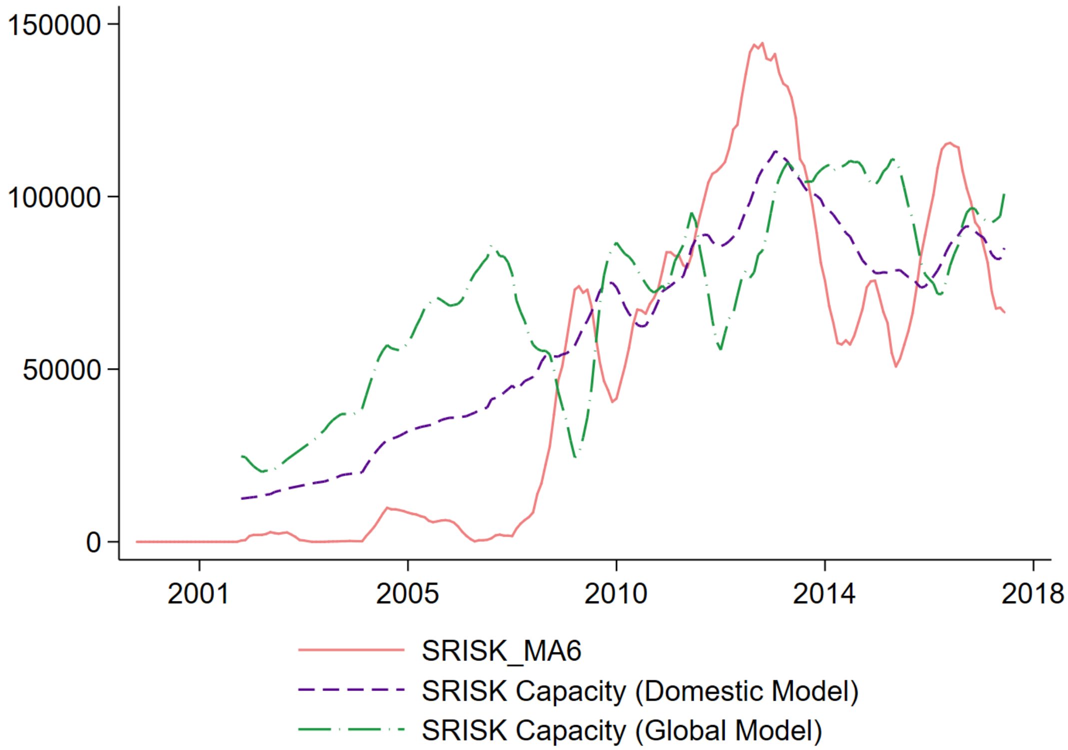

Figure A.37: **Probability of Crisis (%) - Sweden**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

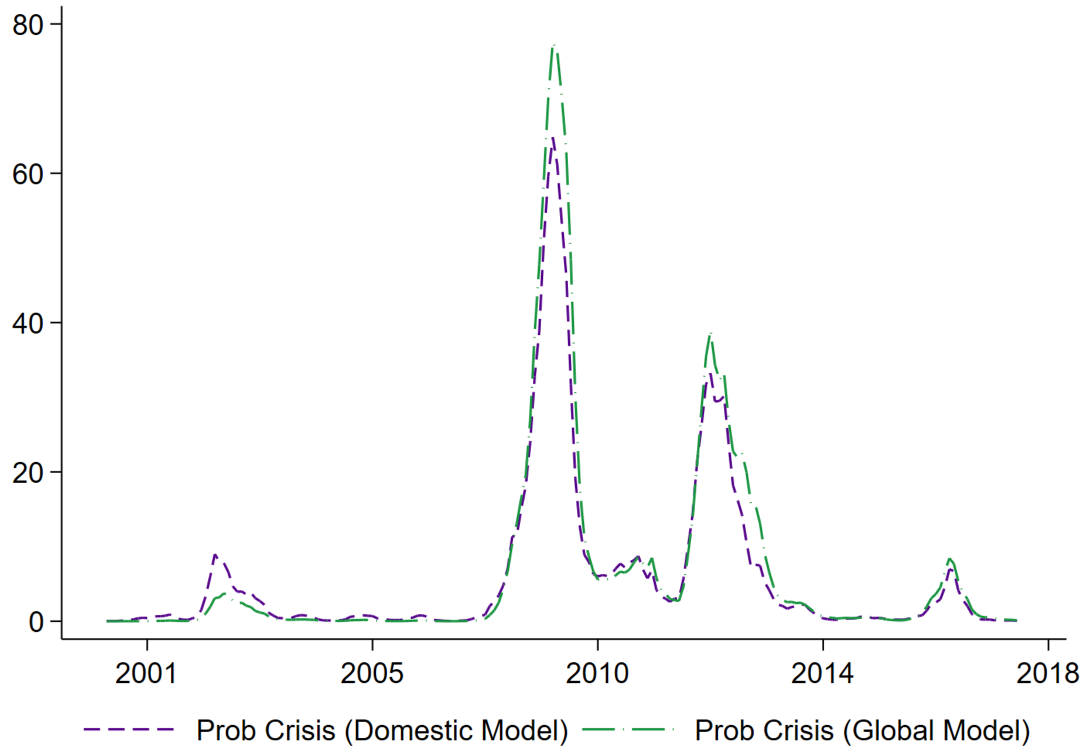

Figure A.38: **SRISK Capacity (USD Million) - Sweden**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

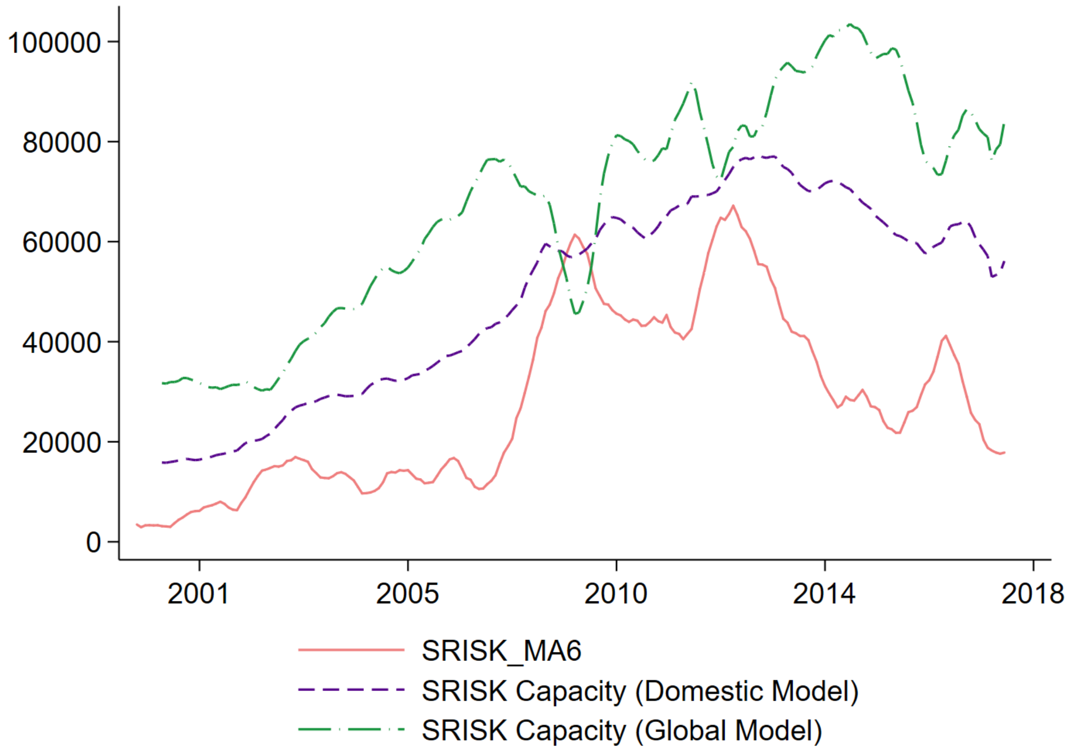

Figure A.39: **Probability of Crisis (%) - Switzerland**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

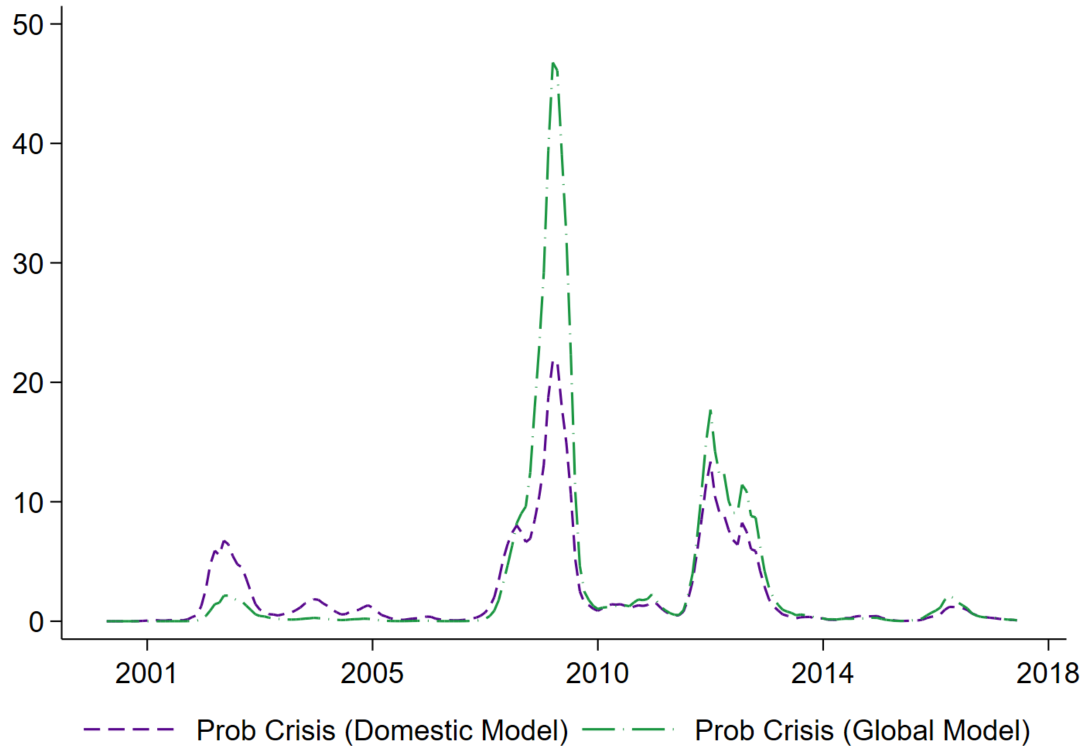

Figure A.40: **SRISK Capacity (USD Million) - Switzerland**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

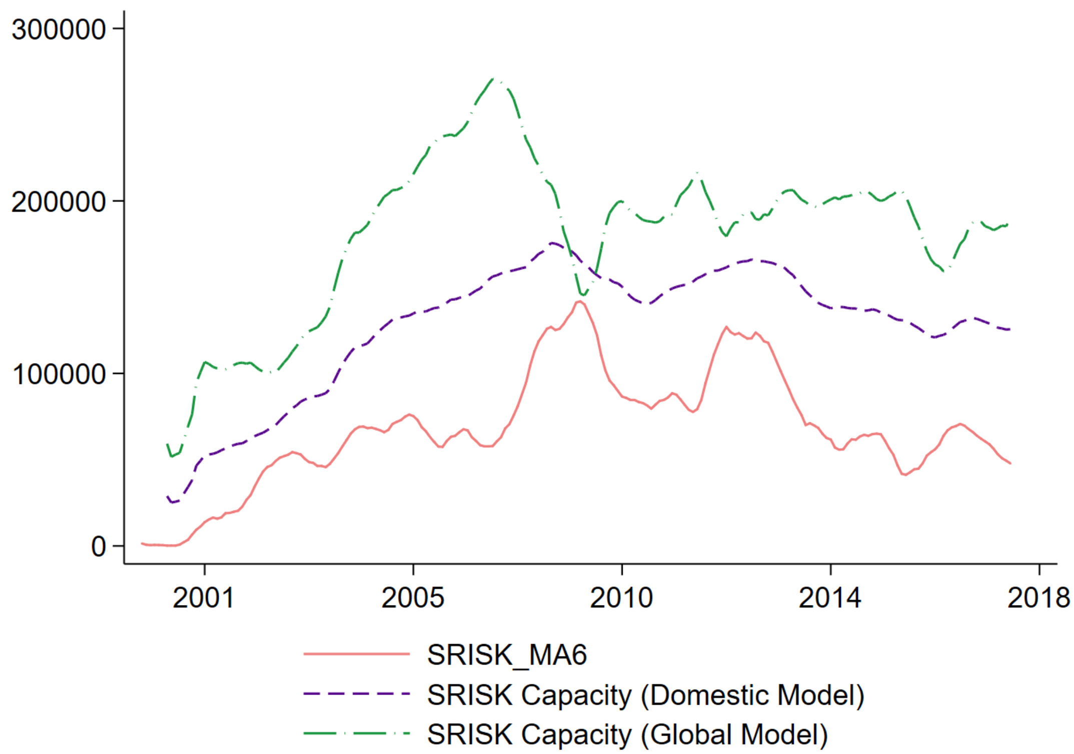

Figure A.41: **Probability of Crisis (%) - Turkey**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

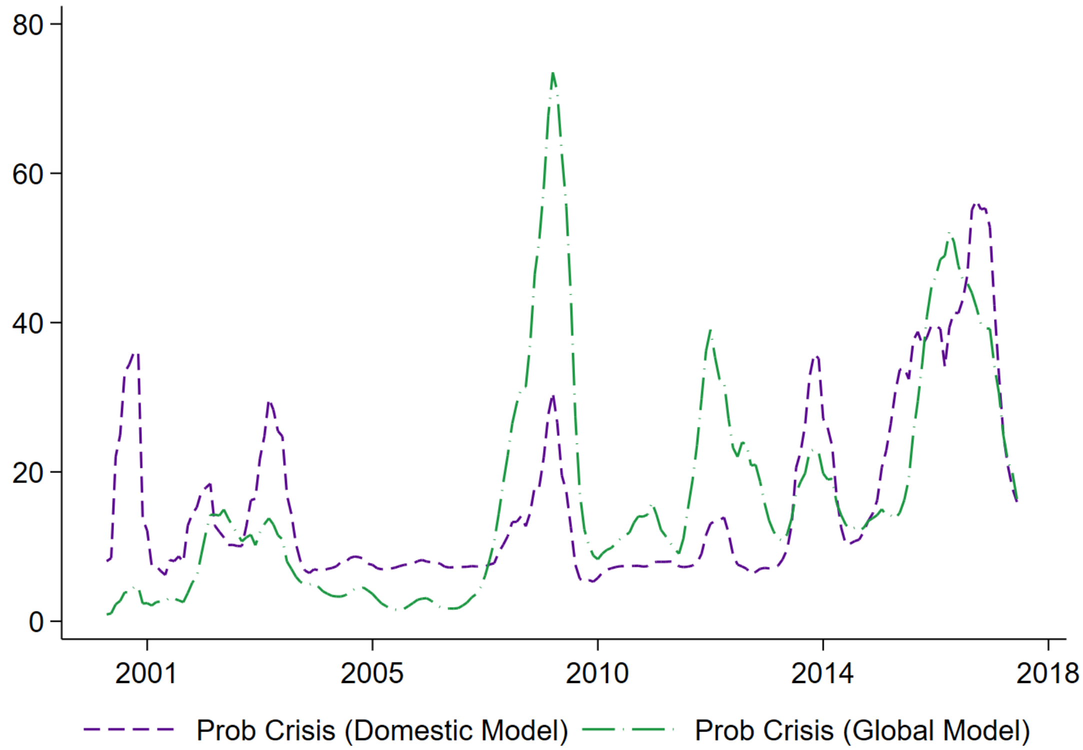

Figure A.42: **SRISK Capacity (USD Million) - Turkey**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

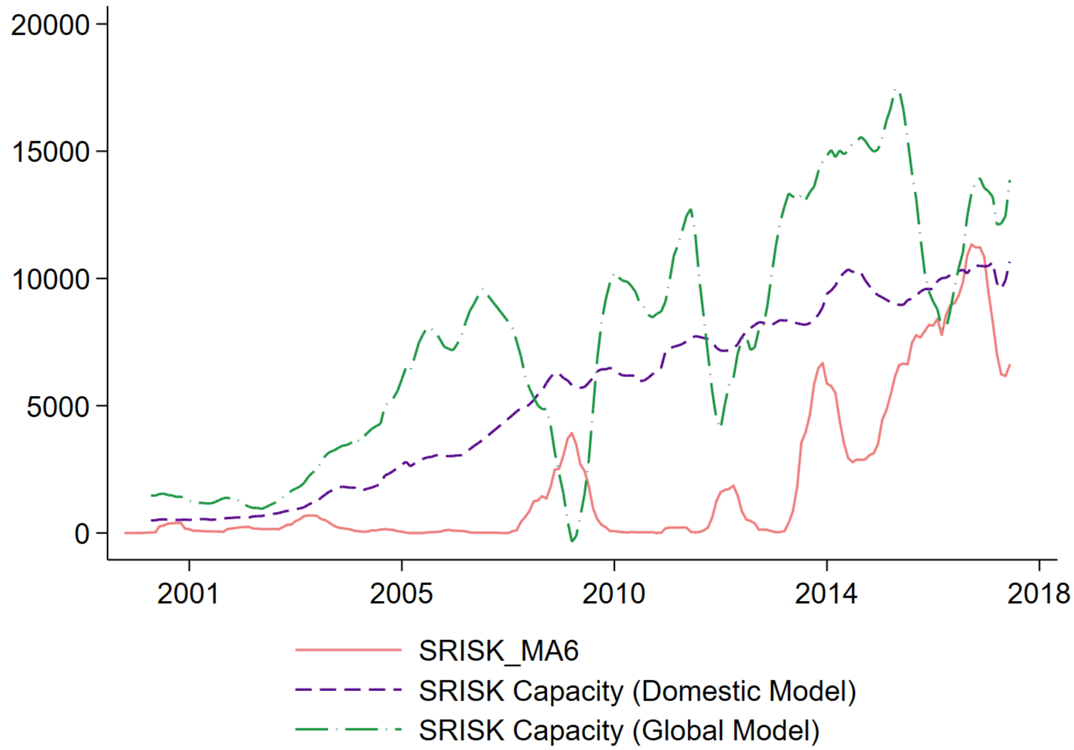

Figure A.43: **Probability of Crisis (%) - United Kingdom**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

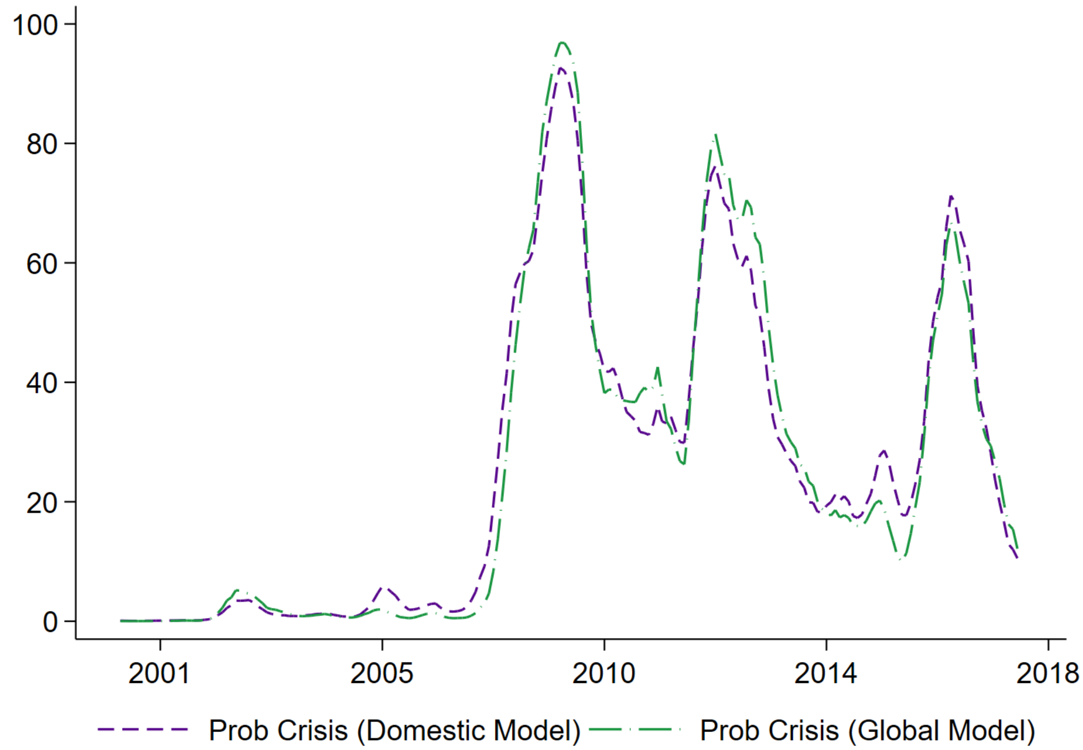

Figure A.44: **SRISK Capacity (USD Million) - United Kingdom**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.

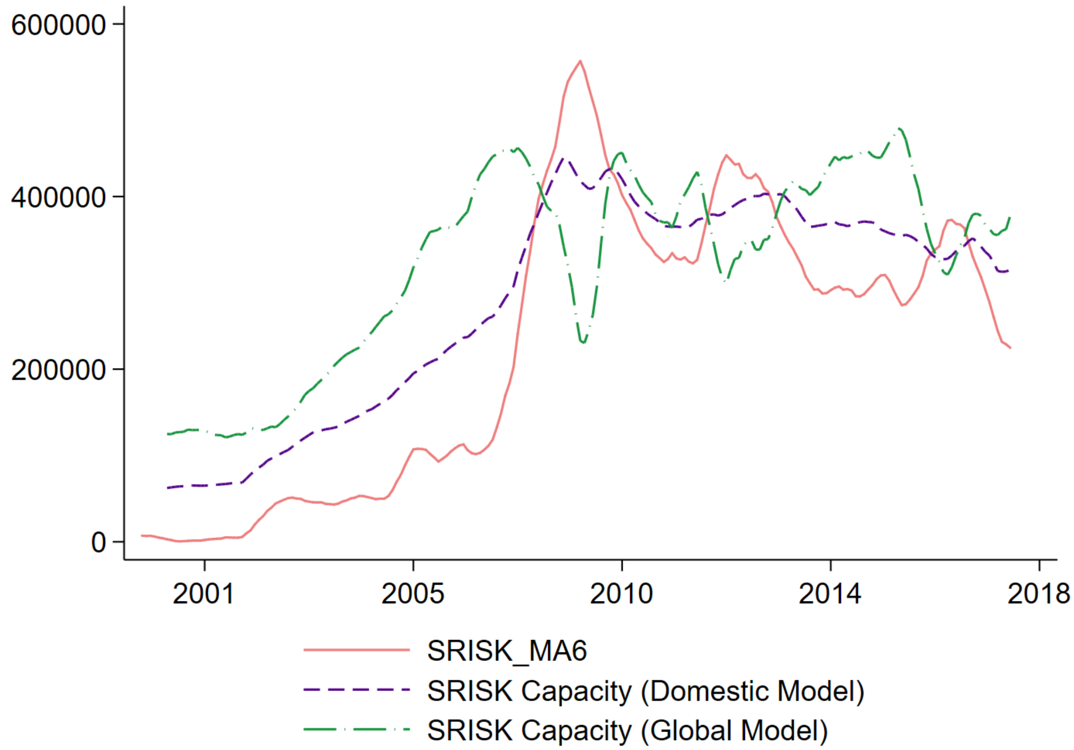

Figure A.45: **Probability of Crisis (%) - United States**

This figure plots the *Probability of Crisis* measures obtained from the domestic and global models. See the text for how the *Probability of Crisis* measure is constructed.

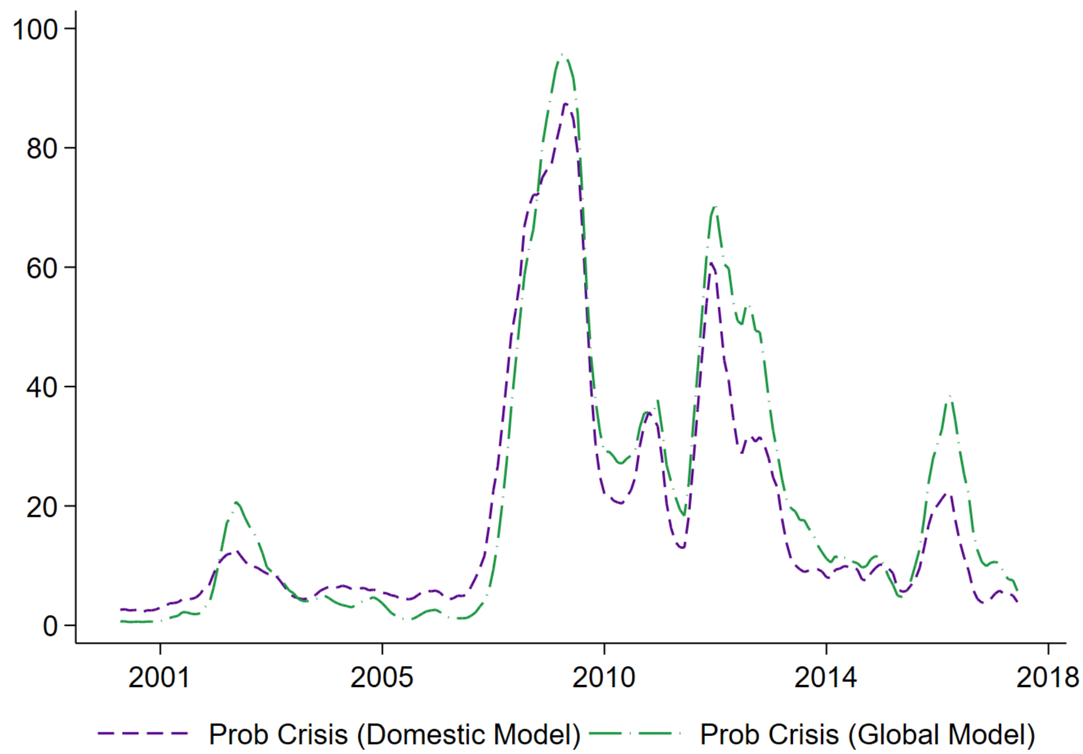

Figure A.46: **SRISK Capacity (USD Million) - United States**

This figure plots the *SRISK Capacity* measures obtained from the domestic and global models relative to the six-month moving-average of SRISK. See the text for how the *SRISK Capacity* measure is constructed.