Clustered Sovereign Defaults*

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Abstract

Clustered sovereign defaults are a recurring phenomenon. This paper investigates the nature of shocks and the mechanism through which these shocks lead countries to clustered defaults. The starting point is a joint estimation of structural parameters driving the output process of 24 countries and a process for the world interest rate. The postulated output process includes transitory and permanent global components as well as transitory and permanent country-specific components. The paper then builds a sovereign default model augmented with financial frictions at the firm level. The model and the estimation process of driving forces are validated jointly when the shocks, estimated independently of the model or of default data, are fed into the model and the model reproduces the clustered default of 1982. The main finding of the paper is that the primary driver of clustered defaults is global shock to the transitory component of output. Contrary to what is commonly believed, the Volcker interest-rate hike was not a decisive factor of the 1982 developing country debt crisis.

JEL classification: F34, F44, H63.
Keywords: Sovereign default, Clustered default, Latin-American debt crisis, Emerging markets

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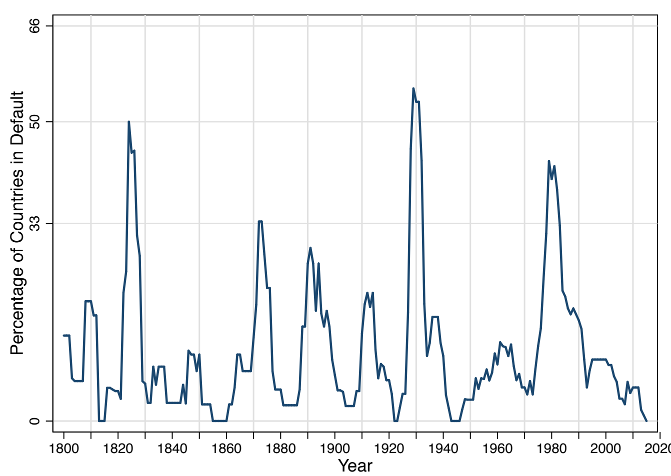
1 Introduction

Historical data on sovereign defaults tells us that *clustered* defaults, where multiple countries default in a relatively short time, is a recurring phenomenon. Figure 1 illustrates[1] that the late 1820s, early 1870s, early 1930s and early 1980s have all been times when a large number of countries defaulted in a 5-year period. In spite of the frequent recurrence of clustered defaults, only a handful of papers[2] have used historical data to analyze the occurrence of clustered defaults. More importantly, these papers have suggested that global shocks played a central role in causing clustered defaults. However, in order to understand clustered defaults, it is not only important to accommodate for the possibility of global shocks but also to identify both their nature and the extent to which they impact countries differentially. Once the global shocks are disentangled from country-specific shocks and a model is developed to study clustered defaults, the framework can be customized for future use by policymakers—be it global policymakers who might be interested in formulating bailout policies or policymakers in large economies who might be contemplating changes to the interest rate. This paper, therefore, builds a quantitative framework which caters, very specifically, to the need of understanding clustered defaults. The framework starts by disentangling different global and country-specific shocks that countries face and then builds a quantitative model to understand the mechanism through which these shocks lead countries to default.

Figure 1: Percentage of defaulting countries in a rolling 5-Year window



Note: Author's Calculations. Data Source: Reinhart et al. (2016). World level data. Number of defaulters increase over time–14 in 1800, 29 in 1825, 36 in 1850, 36 in 1875, 39 in 1900, 44 in 1925, 56 in 1950, 96 in 1975, and 107 in 2000. 278 overall defaults from 1800 to 2015.

[1]There are six peaks between 1800 and 2015 but if I impose the requirement of calling episodes with more than one-third countries defaulting as clustered defaults, I am left with four clustered defaults.

[2]Reinhart and Rogoff (2011b), Bordo and Murshid (2000), Kaminsky and Vega-Garcia (2016) etc.

The necessity of having a separate framework arises from the fact that most of the research on sovereign default focuses on *idiosyncratic* defaults; and these studies look at countries in isolation. As a byproduct, shocks are considered country-specific and there is no role for global shocks in default decisions. Thus, a default where output goes down by 9% due to country-specific shocks and 1% due to global shocks would be treated the same way as a default where output goes down by 9% due to global shocks and 1% due to country-specific shocks because, in aggregate, the output went down by 10% in both cases. This is precisely why the formal setup of idiosyncratic defaults does not fit the one that is needed for clustered defaults. This paper addresses the need of having a setup through a quantitative framework that can analyze clustered defaults and situations like above, likewise.

The quantitative framework that I develop in this paper is based on the traditional model of Eaton and Gersovitz (1981); Arellano (2008); and Aguiar and Gopinath (2006), and enables this paper to answer three important questions: First, are global shocks necessary in order to explain clustered defaults? Second, which global shocks—global shocks to transitory or permanent component of output or world interest rate shocks—matter? Third, can the quantitative framework generate the 1982 default cluster as observed in the data?

To answer these questions, the paper is built in three parts. The first part deals with identification of various global and country-specific shock processes. The second part uses the shock processes identified in the first part to show a significant contribution of global shocks—common-global shocks to transitory component of the output and the shocks to world interest rate—in leading countries toward clustered defaults. The third part develops a quantitative model of sovereign default to capture the mechanism through which these shocks lead countries to clustered defaults. The results from the model confirm the empirical finding that global transitory shocks contribute the most in generating clustered defaults. The model also shows that the quantitative model *does* predict a cluster during 1982 which is in line with the data both in terms of timing and the magnitude. Last, in regards with generating a cluster, the model *does* show that fluctuations in interest rate might lead to clustered defaults but, contradicting a widely held notion, the model also plays down the impact of the Volcker interest-rate hike in causing the clustered default of 1982.

The first part is crucial as it deviates significantly from the existing literature on sovereign defaults to capture the effect of global shocks on output of borrowers. It postulates an output process for every country and accommodates for the presence of five shocks—country-specific transitory and permanent shocks to output; global transitory and permanent shocks to output; and world interest rate. Both global output shocks enter the output process of every country as well as the process of world real interest rate. Thus, the estimation of the structural parameters requires a joint estimation with the output growth of all the countries and world interest rate as observables. The estimation is done using the Bayesian method and the time-series of all country-specific and global shocks are backed out using the Kalman smoothing algorithm.

In the second part, the time-series of smoothed out global and country-specific shocks are used to perform preliminary tests in the style of Kaminsky and Vega-Garcia (2016). The empirical tests highlight that global variables are essential in predicting clustered defaults but not in predicting idiosyncratic ones.

The third part builds on the setup of Arellano (2008) and Aguiar and Gopinath (2006) by making three important changes in order to accommodate all five shocks from the estimation part in a sovereign default model. First, it allows for two global and two country-specific shocks to the output process. Second, the output is now produced using labor. Third, and most important, it incorporates the labor market and a financial friction in the form of working-capital constraint on the firm side. The inclusion of working-capital constraint in the model enables world interest rate to influence default decisions through two channels. I call the first channel the *debt-pricing channel* and the second channel the *endogenous output channel*.[3]

The two channels provide a novel way to capture the effect of interest rate movements on default decisions. In first channel, an increase in interest rate also raises the risky-rate on the debt of the borrowers in order for lenders to be indifferent between holding risk-free and risky assets. This causes a decrease in the price of government debt thereby making borrowing costly and influencing the default decisions through *debt-pricing channel*. The second channel is captured through the labor market and the financial friction. The presence of working-capital constraint requires firms to borrow a fraction of wage bill in advance. This borrowing through intra period loans becomes expensive whenever world interest rate rises. This causes labor demand to go down for a given level of wage. In equilibrium, the quantity of labor as well as output go down. Thus, an increase in the interest rate endogenously effects output and influences the default decision.

The rest of the model remains the same and features incomplete markets (due to the presence of single period non state-contingent debt) and risk neutral foreign lenders. When I simulate the model for every country on the time-series of all the shock processes, the model generates the clustered default of 1982. This proves to be a joint validation of the model and the estimated driving forces. Moreover, I find that the transitory global shock was most important in generating the clustered default of 1982. This counterintuitive results contra-

[3]The shocks to output or technology effect the output of the country both exogenously and endogenously (through the labor market) but changes in interest rate work only through the endogenous channel (via the labor market).

dicts the finding of Aguiar and Gopinath (2006), who attribute defaults to permanent rather than temporary shocks. The mechanism that drives this result depends on two features: convex output costs of default and high persistence of global temporary shocks. The convex output cost assumption[4] makes transitory shocks more important than permanent shocks in leading countries to default; while high persistence of global transitory shocks makes global transitory shocks more important than the country-specific transitory shocks.

The intuition for how convex costs influence the result lies in the different nature of transitory and permanent shocks. After a negative transitory shock, the output goes down today but it improves later on. Thus, the cost of default tomorrow is much higher than the cost of default today. This makes countries to prefer default after a negative transitory shock. Since lenders endogenize this, the level of debt that countries can hold after negative transitory shock is much smaller than the average level. This makes the debt distribution hugely spread out in the presence of only transitory shocks. Thus, after few positive shocks to output, the borrowing countries increase the debt holding so much that a negative shock at that point leads to default because the required deleveraging to avoid default is too big. This channel is even more pronounced when transitory shock is persistent because debt distribution becomes even more spread out. For negative permanent shocks, on the other hand, the output goes down today but it goes down even more tomorrow. The cost of default is therefore more today and the countries prefer to delay default. Since lenders endogenize this, the countries are offered a higher level of debt and the debt distribution is concentrated around the mean. Thus, when a country faces a negative shock after a series of positive shocks, the required deleveraging is still small. This makes countries prefer deleveraging over default after permanent shocks.

Last, even after incorporating both the channels through which interest rate can have an effect on default decisions, the full version of the model shows that the Volcker interest-rate hike was not a decisive factor for the clustered default of 1982.

The remainder is structured as follows. Section 2 discusses the related literature and the contribution of this paper to the literature. Section 3 covers the data used in the paper and defines idiosyncratic and clustered defaults. Section 4 discusses the estimation process of global and country-specific shocks. Section 5 performs the empirical exercise. Section 6 builds the model of clustered sovereign default. Section 7 concludes.

[4]The output cost assumption, although ad-hoc, is similar to the one used by Chatterjee and Eyigungor (2012) and Uribe and Schmitt-Grohé (2017). More recently, Hébert and Schreger (2017) estimate output cost of default for the Argentinean default of 2001 and the results point toward confirming the assumption. There are some other papers like Mendoza and Yue (2012) and Na et al. (2015) where convex cost arise endogenously through the model, hence providing some micro-foundations to the assumption of convex output cost of default.

2 Related Literature

The foundation of the model built in the paper is based on the seminal work of Eaton and Gersovitz (1981); and the subsequent works of Arellano (2008) and Aguiar and Gopinath (2006); who develop a quantitative framework for the analysis of debt and default decision of countries. Unlike these papers, this paper focuses on clustered defaults by studying the impact of global shocks on default decisions. The model captures the effect of global shocks by introducing global output shocks and stochastic world interest rates in a multi-country setup. To best of my knowledge, (1) introduction of two global output shocks and a real interest rate shock; (2) the joint estimation of the shocks processes in a multi-country setup; and (3) capturing the effect of world interest rate shocks (through *debt pricing channel* and *endogenous output channel*) on default decisions; have not been done in the sovereign default literature. The introduction of stochastic world interest rate and its two channels enable this paper to study the effect of interest rate changes on defaults. This paper, therefore, becomes the first in sovereign default literature to quantitatively study the impact of Volcker interest-rate hike on the emerging market debt crisis of 1982.

This paper introduces two global output shocks and a real interest rate shock in the output specific of every country and the specification of world interest rate. This modification makes the output of all the countries dependent on global shocks and requires a joint estimation of the parameters. Using the Bayesian method, I estimate the distribution of 196 parameters with data on the output of 24 countries and world interest rate. An estimation of this type and scale has not been used in sovereign default literature. In other literature, there are some studies – Kose et al. (2003), Kose et al. (2008), Miyamoto and Nguyen (2017) – who use similar dynamic factor method approach to disentangle different global and country-specific shocks.

The full version of the estimation includes not only the global and country-specific shocks but also the endogenous effect of world interest rate changes on the output of different countries using a reduced form. This mechanism to capture the effect of interest rate changes in the US on the output of emerging countries is also micro-founded in the model part of the paper. There is a methodological contribution of this paper to the literature that estimates the effect monetary shocks in the US on the rest of the world. Georgiadis (2016) and Dedola et al. (2017) use VAR methodology to estimate the same effect while Iacoviello et al. (2018) use local projections method. In contrast, this paper micro-founds a transmission mechanism in a general equilibrium model and estimates the structural parameters of the model using the Bayesian method to capture the effect of interest rate changes. The sensitivity of output to interest rate changes estimated in this paper falls in the same range as the ones in the aforementioned papers, validating both the model and the estimation procedure.

To capture the effect of changes in world interest rate shocks through a model, this paper uses working-capital constraints which is not very common to the sovereign default literature. The form of working-capital constraints used in this paper is borrowed from the small open economy setting of Uribe and Yue (2006). Papers like Mendoza and Yue (2012), Padilla (2013), and Mallucci (2015) use working-capital constraints in sovereign default literature as well but in a different setting and to answer different questions.

This paper uses a multi-country setup to study clustered defaults. There are a few other papers who also use multi-country setup to study the risk contagion between countries. For example, in Arellano et al. (2017) and Park (2014), the default premiums of countries are linked because lenders are common and risk-averse. Thus, an idiosyncratic shock to a particular country can propagate to other countries causing risk premiums to co-move. There are a number of differences between this paper and the contagion papers that I have mentioned. First, the contagion papers are mainly focused on the recent European debt crisis where only Greece defaulted whereas this paper focuses on clustered defaults where a much bigger number of countries have defaulted in the past. Second, the success of the model for papers on contagion is measured by matching the co-movement of spreads whereas in this paper I match the default events by 19 countries over a period of 40 years. Lastly, the channel through which countries affect each other in the papers of contagion is the presence of risk-averse lenders whereas in this paper lenders are assumed to be risk neutral. Shocks that lead multiple countries to default propagate either through output decline or through increased world interest rate. Borri and Verdelhan (2011) features correlated shocks between the borrowing countries and the lending countries along with risk aversion on the lender side. This paper does not assume correlated shocks between borrowers and the lenders as Borri and Verdelhan (2011). It has global shocks which affect different borrowers differently whereas lenders remain risk neutral.

There are some other papers that illustrate different mechanisms which lead countries to idiosyncratic defaults. For example, in Lizarazo (2013) the mechanism works through the presence of risk-averse lenders, in Pouzo and Presno (2016) through the presence of uncertainty-averse lenders. Since these mechanisms work through the lender, a shock to the lender can propagate to multiple borrowers in a multi-country setup and can cause clustered defaults. The renegotiation channel studied in Benjamin and Wright (2009) and also used in Arellano et al. (2017) in conjunction with risk-averse lender can also cause multiple countries to default at the same time. Bocola and Dovis (2016) and Lorenzoni and Werning (2013) study the role of expectations in self-fulfilling defaults and slow-moving crisis, respectively. Since these mechanisms work through the presence of multiple equilibria or sunspots, it is another plausible mechanism to generate clustered defaults. This paper neither favors nor rejects any of these explanations. Contrarily, as long as these mechanisms are in place and can slow down the output of multiple borrowing countries together, this paper will capture all these mechanisms. The only requirement is that the slowdowns in output happen for multiple countries and they are captured as a global output shock in the estimation procedure of this paper.

Lastly, this paper also contributes to the empirical literature on clustered defaults. Most notable papers that focus on clustered sovereign defaults are Bordo and Murshid (2000) and Reinhart and Rogoff (2011a). Bordo and Murshid (2000) look at the possibility of contagion in crisis episodes spanning three different eras. By comparing the extent of co-movements across markets before and after the onset of a crisis, they find little evidence of the contagion phenomena in the more recent crises in Asia and Latin America. Reinhart and Rogoff (2011a) document the clustering effect of crises, calling them serial defaults, using data of more than two centuries. Kaminsky and Vega-Garcia (2016) remains one of the few papers to perform a detailed empirical investigation for the possibility of global shocks – panics to financial centers – in causing clustered defaults. They use a dataset on 7 Latin American countries from 1820 to the great depression that captures a total of 27 defaults to show that global shocks are essential in predicting clustered defaults. Furthermore, they attribute the international collapse of liquidity and the growth slowdown in the financial centers to be responsible for clustered defaults. The default definitions, as well as the preliminary empirical setup used in this paper, follows Kaminsky and Vega-Garcia (2016) but this paper uses a dataset of 92 countries and 146 sovereign defaults between 1975 and 2014. Contradicting the results of Kaminsky and Vega-Garcia (2016), the empirical setup shows that global transitory shocks rather than permanent ones were mainly responsible for the clustered default of 1982.

3 Clustered and Idiosyncratic Sovereign Defaults

3.1 Data

The paper is divided into three main sections: the estimation part, the empirical part and the model part. I start with the estimation part where data on country-specific output growth and world interest rate is used. In the empirical part, the paper uses the Kalman smoothed time series of output shocks that comes out of the estimation part. The paper also uses some data on defaulting countries and some global variables to evaluate their explanatory power for the default decision of the country. In the model part, calibration of different parameters require country-specific data.

For the estimation of parameters that drive the output process of different countries, I use output growth and world interest rate data as observables. I use data on the real GDP of all borrowers along with some of the developed countries[5] that haven't defaulted in the sample period. I construct the data on the world real interest rates by using the 5-year Treasury constant maturity rate and adding a market risk spread to it. This spread is constructed by using Moody's seasoned BAA-rated corporate bonds and Moody's seasoned AAA-rated corporate bonds. Both of these are retrieved from Federal Reserve Economic Data (FRED), Federal Reserve Bank of St. Louis. I further adjust the interest rate for inflation by using expectations for one-year-ahead annual average inflation measured by the GDP price index from the Survey of Professional Forecasters, Federal Reserve Bank of Philadelphia.

For the empirical analysis, in order to capture the output shocks, I use Kalman smoothed time-series of country-specific and global components of the output process for every country. This time-series comes directly from the estimation part and it only 49 defaulting countries and 87 defaults for the period of 1975-2014. I test the robustness of results by using HP-filtered components of GDP which provides a larger set of countries.[6] This expanded set of countries also covers the sovereign defaults between 1975 and 2014. The data on these default episodes come from Uribe and Schmitt-Grohé (2017). As summarized in Table 1, this dataset contains a set of 92 countries that choose to default 146 times between 1975 and 2014. The largest share of these defaults comes from two regions: (1) Africa and the Middle East, where 42 countries led to 65 defaults, and (2) Latin America and the Caribbean, where 28 countries defaulted 51 times in total. The dataset contains not only the years of default but also the number of years[7] subsequent to the default episode for which the countries remained in default status.[8] Additionally, the paper uses country-specific data on total external-debt

[5] France, Italy, Japan, United Kingdom, and United States–the biggest countries at the start of the data period.

[6] The global shocks are proxied by using HP-filtered cycle and trend components of GDP for the US.

[7] The data contain start and end dates of default. For example, Peru had one default with a start date of 1978 and end date of 1978, and Argentina had a default with start date of 1982 and end date of 1993. I use the date of start of default as the default date and calculate the number of years the country remained in default for every default episode. The number of years in the Peruvian default of 1978, for example, is calculated as 1, and the same for the Argentinean default of 1982 is calculated as 12.

[8] The definition of a country in default status is as follows, from Uribe and Schmitt-Grohé (2017), who in turn follow the Standard and Poor's specification: *Standard and Poor's defines default as the failure to meet a principal or interest payment on the due date (or within a specified grace period) contained in the original terms of a debt issue (Beers and Chambers, 2006). This definition includes not only situations in which the sovereign simply refuses to pay interest or principal, but also situations in which it forces an exchange of old debt for new debt with less-favorable terms than the original issue or it converts debt into a different currency of less than equivalent face value. A country is considered to have emerged from default when it resumes payments of interest and principal including arrears. In cases of debt renegotiation and restructuring, the country is assumed to rejoin the markets when the rating agency concludes that no further near-term resolution of creditors' claims is likely.*

to GDP ratio of countries. I use the data on net foreign assets of the borrowers as a fraction of GDP from the extended version of Lane and Milesi-Ferretti (2007) to proxy for total external-debt to GDP ratio. Another proxy that I use is the data on government debt as a fraction of GDP from Abbas et al. (2010). Lastly, spot crude oil price data, another global variable, are also retrieved from FRED. I adjust the oil price for inflation using consumer price index data for all urban consumers, also retrieved from FRED.

Table 1: Summary Stats: Default Episodes

	No. of Countries Defaulting	No. of Defaults
World	92	146
Africa & Middle East	42	65
Latin America & Caribbean	28	51
Europe & Central Asia	15	19
Rest of Asia & Pacific	7	11

For the model part, I use the same GDP data and the world real interest rate data that I used during estimation exercise. For calibration of the model, I use data on default frequency from Reinhart and Rogoff (2011b). When unavailable, I use the data from Uribe and Schmitt-Grohé (2017), which covers a shorter period. To get an estimate of debt that lenders can't recover from the borrowers, I use average haircut data from Cruces and Trebesch (2013). The data on net foreign assets as a fraction of GDP are the same as in the empirical part. The data on average years in default comes from Reinhart and Rogoff (2011b). If unavailable, I again use the data from Uribe and Schmitt-Grohé (2017).

3.2 Definition

Clustered defaults are those default episodes that happen during periods where a great number of countries are defaulting on their external debt obligations. In order to capture the clustered defaults, this paper follows the same definition as proposed by Kaminsky and Vega-Garcia (2016). The first step in their approach is to identify the years in which a large fraction of countries default and then the defaults that happen in these years are classified as clustered defaults.

Following Kaminsky and Vega-Garcia (2016), I constitute 5-year rolling windows at every year from 1975 to 2010.[9] For every such window, I count the number of countries that defaulted in the 5-year window.[10] If the total number of countries defaulting in a rolling

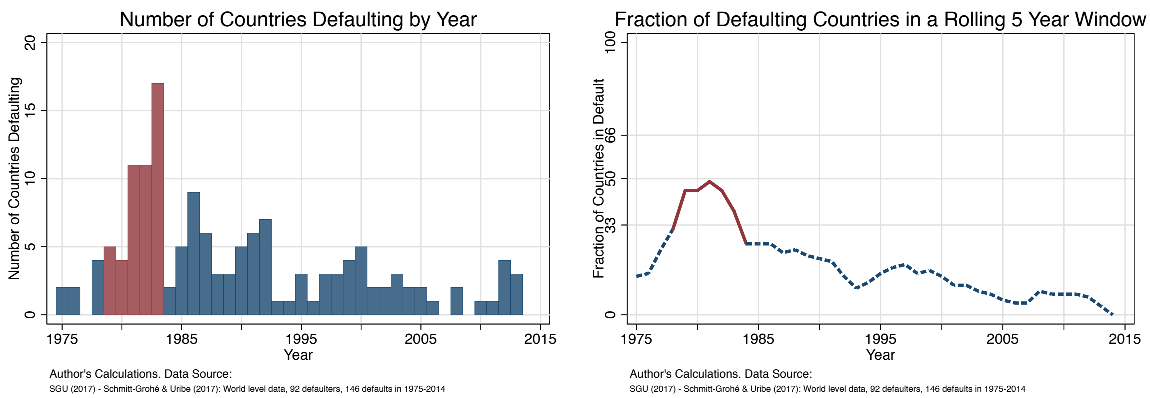
[9]Since the data on default goes from 1975 to 2014, the last rolling window containing 5 years is 2010.

[10]The paper focuses on the number of countries that default and not on the number of defaults. Peru, for example, defaults in 1978 and 1980. Thus, in the rolling 5-year window starting in 1978, Peru will be counted only once.

window is more than one-third of all countries that defaulted during 1975-2014, I call the 5-year rolling window a “window of clustered default” and all the default episodes that belong to the starting year of that window as “clustered default episodes”.[11] All remaining defaults are idiosyncratic defaults.

3.3 Categorizing Defaults as Clustered or Idiosyncratic

Figure 2: Countries defaulting in a 5-year rolling window



The left panel shows the number of countries in default in every year from 1975-2014. The right panel shows the fraction of countries defaulting in a 5-year rolling window starting every year. The maroon line highlights the period of clustered defaults, and the blue line highlights idiosyncratic defaults.

Given the definition of clustered and idiosyncratic default episodes and a total of 92 countries that defaulted at least once in the period 1975-2014, any 5-year window with 31 or more countries defaulting will be classified as a clustered default window. It is evident from Figure 2 that five 5-year rolling windows constitute clustered default windows: 1979-1983, 1980-1984, 1981-1985, 1982-1986, and 1983-1987. Thus, defaults in 1979, 1980, 1981, 1982, and 1983 become clustered defaults.

The first row of Table 2 shows that out of 146 defaults, 48 fall in the category of clustered defaults by our definition. Automatically, the remaining 98 defaults become idiosyncratic defaults.

Alternatively, if one believes that the shocks, defaults, business cycles, etc. are more correlated across countries that are geographically close to each other, systemic and idiosyncratic defaults can also be defined at the region level. To do this, I count the total number

[11] The window 1983-1987 contains 35 different defaulters. Out of this 35, 17 countries defaulted in 1983, 2 in 1984, 5 in 1985, 7 in 1986, and 4 in 1987. Only the defaults in the first year of the window–i.e., 1983–are considered part of a clustered default episode, and not the ones in the subsequent years of this 5-year rolling window.

Table 2: Default Classification: World Level and Region Level

Region Name	No. of Defaulting Countries	Total Number of Defaults	Number of Clustered Defaults	Years of Default for Clustered Defaults
World	92	146	48	1979-1983
Africa & Middle East	42	65	34	1979-1985
Latin America & Caribbean	28	51	22	1978-1983
Europe & Central Asia	15	19	8	1988-1991
Rest of Asia & Pacific	7	11	4	1981-1983,1993-1997

of countries defaulting in a particular region between 1975 and 2014, then look for 5-year rolling windows in every region in which more than one-third of the countries belonging to the respective region default. These 5-year windows will be the clustered default windows for that region.

Figure A1 in the appendix shows the years of clustered defaults for regional classification. The summary for the same is presented in Table 2. Thirty-four out of 65 defaults in Africa and the Middle East, 22 out of 51 in Latin America and the Caribbean, 8 out of 19 in Europe and Central Asia, and 4 out of 11 in Rest of Asia and the Pacific are classified as clustered defaults. Thus, with the regional classification, a total of 68 defaults fall into the category of clustered defaults, while the remaining 76 fall into the category of idiosyncratic defaults. Overall, depending on the classification, 33% to 45% of all defaults between 1975 and 2014 were clustered.

This paper, henceforth, considers the world-level classification for the analysis of clustered and idiosyncratic defaults. All of the results obtained remain robust to the regional classification as well. Thus, the results are independent of the classification method.

4 Estimating the Global and Country-Specific Shocks

The output of every country is assumed to have two country-specific and two global components. I postulate time-varying processes for these components of output. The parameters governing these processes and those of the output function are then estimated using the Bayesian method.

I start by assuming a simple output function that is driven only by exogenous shocks and estimate the parameters governing such an output process. Subsequently, I go to the full version of the output function where output is produced using labor. I then make some identification assumptions to estimate the parameters in this full version. The purpose of this full version is to capture the effect of changes in world interest rate shocks on the output of emerging economies.

4.1 The Basic Version

The output process of every country is assumed to have transitory and permanent shocks as in Aguiar and Gopinath (2006). The modification here is that both the shocks have one country-specific component and one global component. Thus, the global shocks enter the output process through both - the transitory and the permanent component.

As the name suggests, global shocks effect the output of all the countries. The way these global shocks effect different countries is different and therefore, the way the global shocks enter the output process of different countries is also different. Thus, the same global shock can affect, for example, Argentina in a completely different way as it affects Mexico.

The presence of global shocks in the output process of all the countries makes it necessary to observe the output processes of all the countries jointly in order to estimate the parameters governing the output, the country-specific shock processes and the global shock processes.

I start by writing down the output of a country c, at a given time t (omitted from the equation for convenience) as:

$$Y^c = e^{z^c + \alpha_z^c z^w} X^c (X^w)^{\alpha_X^c}$$

where a superscript c represents a country and a superscript w represents the world.[12] Variables with c superscript, z^c and X^c are country-specific transitory and permanent components of output. Similarly, z^w and X^w are global transitory and permanent components of output. In the log specification of output, the global components – z^w and $\ln(X^w)$ – enter with a multiplicative factor of α_z^c and α_X^c, respectively. Intuitively a global shock can transmit to the local economy depending on the interaction of the country with the global economy via financial markets, trade of good or services, etc. If this interaction is negligible, the values of both the α's would be close to zero. On the contrary, if the interaction is sizable, we will have non-zero value of both the α's. In terms of natural logarithms, the equation can be written as:

$$y^c = z^c + \alpha_z^c z^w + \ln(X^c) + \alpha_X^c \ln(X^w)$$

Both the transitory components, z^c and z^w, are assumed to follow an $AR(1)$ process with persistence ρ_z^c, ρ_z^w and standard deviation σ_z^c, σ_z^w respectively. The long run mean of both the transitory components is assumed to be 0.

$$z_t^c = \rho_z^c z_{t-1}^c + \epsilon_{z,t}^c$$

$$z_t^w = \rho_z^w z_{t-1}^w + \epsilon_{z,t}^w$$

[12] The de-trended version of output will therefore be $\tilde{Y^c} = Y^c/(X_{-1}^c \times \mu_g^c \times (X_{-1}^w)^{\alpha_X^c} \times (\mu_g^w)^{\alpha_X^c}) = e^{z^c + \alpha_z^c z^w} g^c (g^w)^{\alpha_X^c} / \mu_g^c$, where $g^c = X^c / X_{-1}^c$, $g^w = X^w / X_{-1}^w$ and $\mu_g^w = 1$.

The growth rate of the permanent components are given as: $g_t^c = X_t^c/X_{t-1}^c$ and $g_t^w = X_t^w/X_{t-1}^w$. Logarithm of the growth rate in the permanent components, $\ln(g^c)$ and $\ln(g^w)$, follow AR(1) with persistence ρ_g^c, ρ_g^w; standard deviation σ_g^c, σ_g^w; and long run means of g_{ss}^c and g_{ss}^w.

$$\ln(g_t^c/g_{ss}^c) = \rho_g^c \ln(g_{t-1}^c/g_{ss}^c) + \epsilon_{g,t}^c$$

$$\ln(g_t^w/g_{ss}^w) = \rho_g^w \ln(g_{t-1}^w/g_{ss}^w) + \epsilon_{g,t}^w$$

All the persistence levels are assumed to satisfy $|\rho| < 1$ and the shocks are assumed to be normally distributed, $\epsilon \sim N(0, \sigma^2)$.

State Space Form

Treating the output growth rate for the countries as observable, output equation for country c can be rewritten as:

$$y_t^c - y_{t-1}^c = z_t^c - z_{t-1}^c + \alpha_z^c(z_t^w - z_{t-1}^w) + \ln(g_t^c) + \alpha_X^c \ln(g_t^w)$$

This measurement equation for country c can be written in the state space form with 3 global state-variables – z_t^w, z_{t-1}^w, $\ln(g_t^w/g_{ss}^w)$ – and 3 country-specific state-variables – z_t^c, z_{t-1}^c, $\ln(g_t^c/g_{ss}^c)$.

$$\Delta y_t^c = \ln(g_{ss}^c) + \alpha_X^c \ln(g_{ss}^w) + \Delta z_t^c + \alpha_z^c \Delta z_t^w + \ln(g_t^c/g_{ss}^c) + \alpha_X^c \ln(g_t^w/g_{ss}^w)$$

As the equation suggests, the 3 global state-variables – z_t^w, z_{t-1}^w, $\ln(g_t^w/g_{ss}^w)$ – have an effect not only on the growth rate of output for country c, but also for all other countries. Since the state-space equation for all the countries will have these global state-variables, the contemporaneous observable is an $(nc \times 1)$ (where nc is the total number of countries) vector of output growth of individual countries. That is, in order to estimate the parameters related these global state-variables, the state space equations of all the countries need to be stacked one over the other for every time t and be treated as an observable at time t. This combined state space equation can be used to estimate the parameters of all the countries together. The measurement equation of this state space form will therefore look like:

$$\Delta y_t = W + V \cdot \theta_t$$

The dimension of Δy_t is $(nc \times 1)$. W is also $(nc \times 1)$ and it is time invariant. V is $(nc \times (3 * nc + 3))$ and it is time invariant as well. The state variable vector, θ_t, is $((3 * nc + 3)$

$\times 1$). The evolution of state vector (transition equation) can be represented as:

$$\theta_t = K \cdot \theta_{t-1} + \lambda_t$$

Section B.1 of appendix reproduces the state-space form and gives formulation of all the vectors and matrices related to the state-space form.

Estimation of Country Specific and Global Parameters

I include the output growth of all the defaulting countries from Latin American and the Caribbean as observable. This constitutes a a total of 19 countries. If I estimate the latent states using this set of 19 countries, my estimates for global state-variables will possibly be biased due to the presence of defaulting countries only. In order to avoid this bias, I add 5 developed countries – France, Japan, Italy, United Kingdom, and United States – taking the total number of countries to 24.

Since the output process of every country is comprised of four components, I have (i) two country-specific shock processes – z^c and $\ln(g^c)$ – for every country, (ii) two global shock processes – z^w and $\ln(g^w)$ – and (iii) two coefficients corresponding to the global shocks – α_z^c and α_X^c – for every country. For every component, I estimate the persistence and the variance of the process. With the data on 24 countries I thus have 96 parameters related to country-specific shocks (ρ_z^c, ρ_g^c, σ_z^c and σ_g^c for every c). Moving on to global shocks, I normalize the standard deviation of the world shocks to 1 without loss in generality. This is because α_z^c and α_X^c can account for any any scale effect arising from a different value of standard deviation.[13] Once the standard deviation of the world shocks is normalized to 1, the direction and the volatility of the effect of world shocks on a specific country will be governed by country specific factors: α_z^c, α_X^c. Thus, this adds 48 more parameters that govern the effect of global transitory and permanent components on the output of individual countries. Lastly, there remain 2 persistence parameters for global permanent and transitory shock processes. Together there are 146 parameters to estimate.

Average growth rate of countries, μ_g^c, is observable in the data and thus I assume that the steady state level of growth rate in the country-specific permanent component, g_{ss}^c, is same as the former. I also make the assumption that $g_{ss}^w = 1$. One last identification assumption remains. I restrict α_z^c and α_X^c to be positive. The reason is that a particular time series of z^w and $\ln(g^w)$ and the corresponding multiplicative parameter values, α_z^c and α_X^c, generates a

[13]Both z^w and $\ln(g^w)$ appear along with the α_z^c and α_X^c for every individual country. Writing the process of z^w in $MA(\infty)$ rather than $AR(1)$ form, we get: $\alpha_z^c z^w = \alpha_z^c(\epsilon_{z,t}^w + \rho_z^c \epsilon_{z,t-1}^w + (\rho_z^c)^2 \epsilon_{z,t-2}^w + (\rho_z^c)^3 \epsilon_{z,t-3}^w + ...\infty) = \alpha_z^c \cdot \sigma_z^w (e_{z,t}^w + \rho_z^c e_{z,t-1}^w + (\rho_z^c)^2 e_{z,t-2}^w + (\rho_z^c)^3 e_{z,t-3}^w + ...\infty)$, where $e = \epsilon/\sigma$ is standard normal. This shows that we can only observe the product, $\alpha_z^c \cdot \sigma_z^w$ and hence it is safe to normalize σ_w^z as well as σ_w^g to 1.

particular time series of global shocks to every country's output. If there are no restrictions on α, a time series which is negative of z^w and $\ln(g^w)$ along with opposite signs of α_z^c and α_X^c will also generate the same contribution to every country's output. To get rid of this multiplicity, I assume that for Venezuela, $\alpha_z^{VEN} > 0$ and $\alpha_X^{VEN} > 0$.

The paper uses Bayesian method to estimate the parameters pertaining the output process of all the countries. I start by using output growth data on 24 countries from 1961 to 2014. I assume a uniform prior on all the parameters and apply Kalman filter to calculate the likelihood given the past data. The calculated likelihood along with the prior produces the posterior likelihood. The Metropolis-Hastings algorithm and the the sequence of posterior likelihoods yield an approximate posterior distribution of all the parameters.

The prior distributions are shown in the Table A5 of the appendix. All the persistence levels, country-specific as well as global, are assumed to have the same uniform prior distribution. Standard deviations of global shocks are normalized to 1 but all the country-specific standard deviations also have the same prior distribution. The prior for α values for Venezuela is between 0.0001 and 2 but all other α values have a uniform prior between -2 and 2. With a Markov chain of 1 million draws, the posterior means of ρ_z^w and ρ_g^w are estimated to be 0.94 and 0.50. The posterior means for the remaining parameters are shown in Table 3. Among all 4 output shocks, global shocks to the transitory component with a persistence of 0.94 is the most persistent shock.

Given that all the prior distributions were assumed to be uniform, the posterior distributions show that they differ significantly from the prior distributions.[14] Table A7 in the appendix shows means and standard deviations of all the estimated parameters. Among all the parameters related to persistent level of shocks, persistence of global shock to transitory component of output is most precisely estimated. This is evident from the standard deviation of ρ_z^w reported to be 0.04 in Table A7. Some of the parameters related to the persistence level are not very precisely estimated. Table A7 shows that posterior distribution of standard deviations are precisely estimated for all the countries. Though mean α values are positive for most of the countries as shown in columns 7 and 8 of Table A7 and the distributions of these α values are also precise, it is difficult to say if the α values differ significantly from 0 for some of the countries.

I use mean values from the posterior estimates of all the parameters and use Kalman smoothing algorithm to smooth out all the latent shocks that different countries face. Figure A5 of the appendix shows the time-series of global transitory and permanent components of output. The top panel shows a big negative transitory shock in early 1980s and then a small negative transitory shock around the great recession. The bottom panel shows multiple

[14]Posterior distributions are not shown here. Only Mean and standard deviations are reported.

Table 3: Bayesian Estimation Results from Basic Model: Posterior means

Country	Posterior (Means)					
	ρ_z^c	ρ_g^c	σ_z^c	σ_g^c	α_z^c	α_X^c
Argentina	0.5751	0.2774	0.0370	0.0190	0.0190	0.0157
Belize	0.4532	0.5530	0.0094	0.0301	0.0058	0.0043
Bolivia	0.6336	0.3433	0.0176	0.0238	0.0052	0.0080
Brazil	0.2672	0.5619	0.0093	0.0248	0.0165	0.0045
Chile	0.6647	0.5342	0.0185	0.0305	0.0234	0.0048
Costa Rica	0.7120	0.2835	0.0158	0.0128	0.0190	0.0015
Dominican Republic	0.7517	0.3894	0.0397	0.0190	0.0146	0.0025
Ecuador	0.6620	0.4509	0.0125	0.0210	0.0064	0.0051
Guatemala	0.4669	0.6373	0.0069	0.0112	0.0121	0.0001
Guyana	0.6988	0.3202	0.0228	0.0277	0.0092	0.0229
Honduras	0.5827	0.3248	0.0130	0.0142	0.0174	-0.0010
Mexico	0.3328	0.3815	0.0094	0.0251	0.0176	0.0041
Nicaragua	0.6416	0.4959	0.0268	0.0485	0.0026	0.0106
Panama	0.7705	0.4015	0.0118	0.0313	0.0085	0.0152
Paraguay	0.5821	0.7096	0.0184	0.0194	0.0173	0.0070
Peru	0.8125	0.4263	0.0126	0.0329	0.0129	0.0214
Trinidad and Tobago	0.6563	0.6455	0.0140	0.0322	0.0113	0.0024
Uruguay	0.5996	0.4348	0.0096	0.0255	0.0151	0.0186
Venezuela, RB	0.6204	0.3278	0.0333	0.0211	0.0227	0.0074

Posterior means for ρ_z^w and ρ_g^w are 0.9414 and 0.5038 respectively

The countries included in the estimation process are 24. 19 defaulting countries from Latin America & Caribbean and 5 non-defaulting developed countries. Parameter estimates are reported only for 19 Latin America & Caribbean countries.

permanent shocks but the ones with the biggest impact are observed during early 1980s and just before 1990s. Both the time series are scaled to the parameters of Argentina. Thus, the time series shows that during early 1980s, Argentina faced a negative transitory shock which took detrended GDP to 9% below 0 in 4 years and the negative permanent shock that took detrended GDP to 7% below 0 in 3 years.

The time series obtained using the Kalman smoothing is used for the empirical exercise performed in the next section. The time series is also used in the model section when I simulate the optimal debt and default decision for all the countries.

4.2 The Full Version

The full version of the estimation process is intended to capture the effect of changes in world interest rate on the output of emerging countries. I start by hypothesizing an output function that is a modified form of the output function used in the baseline version. This full version not only captures the effect of changes in world interest rate on output but can also be micro-founded in a general equilibrium framework. This is done in Section 6.1 when I discuss the model of sovereign default. The mechanism works through labor demand and the working-capital constraint. Through this channel, changes in real interest rate effects equilibrium quantity of labor. Since output is assumed to be produced using labor, output is also effected by interest rate changes.

In the full version, output of a country c at a given time t (omitted from the equation for convenience) is given as:

$$Y^c = A^c (L^c)^{\alpha_L^c}$$

where $A^c = e^{z^c + \alpha_z^c z^w} X^c (X^w)^{\alpha_X^c}$ represents technology level.[15]

The technology, A^c, in full version is exactly the same as the output in baseline version. Thus, the technology level grows with shocks around a trend. The labor, as we know from our macro models as well as the data, is stationary. Even though labor is stationary, it fluctuates along with fluctuations in technology. Thus, labor here is assumed to be dependent on detrended level of technology which make it stationary but at the same time responsive to technology shocks.

Additionally, I assume that labor is inversely proportional to world interest rate. This can happen because production is costly and firms in emerging markets tend to borrow in order to produce. When the interest rates go up, the borrowing cost goes up and this causes labor demand as well as the output to go down. This relationship between labor and interest rate is micro-founded at a later stage when I discuss the model.

The two assumptions together give: $L_t^c = \kappa \tilde{A}_t^c / ((1 + r_t^*)^\eta)$, where κ is a constant and $\tilde{A}$ is de-trended level of technology.[16] The output can, therefore, be rewritten as:

$$Y^c = e^{z^c + \alpha_z^c z^w} X^c (X^w)^{\alpha_X^c} (\kappa e^{z^c + \alpha_z^c z^w} g^c (g^w)^{\alpha_X^c} / (1 + r^*))^{\alpha_L^c}$$

Taking logs, I can write the output growth in the full version as:[17]

[15]I call A_t^c as technology level and the corresponding shocks are shocks to technology but in reality, these shocks can be demand shocks or some other shocks. The purpose of the equation is to capture the shocks to output and in the full version, it is convenient to call the shocks as technology shocks.

[16]This functional form of labor is equivalent to $L_t^c = \kappa(\tilde{A}_t^c)^\mu / ((1 + r_t^*)^\eta)$ since it can be written as $L_t^c = (\kappa_1(\tilde{A}_t^c)/((1 + r_t^*)^{\eta/\mu}))^\mu$. Once I substitue this in the output function, any scale effect of μ can be taking into account by a different value of α_L^c.

[17]This equation of output growth looks exactly like the one that we get from the model which is solved in a general equilibrium framework. The interpretation of coefficients in this equation are slightly different than the ones obtained from the model because the later is based on the parameters of the model.

$$\Delta y_t^c = \psi^c \Delta z_t^c + \psi^c \alpha_z^c \Delta z_t^w + \psi^c \ln(g_t^c) + \psi^c \alpha_X^c \ln(g_t^w)$$
$$- (\psi^c - 1)\ln(g_{t-1}^c) - (\psi^c - 1)\alpha_X^c \ln(g_{t-1}^w) - (\psi^c - 1)\eta^c \Delta r_t^*$$

where $\psi^c = 1 + \alpha_L^c$.

The 4 basic sources of shocks remain the same in the full version as they were in the basic version – z_t^c, z_t^w, $\ln(g_t^c)$, and $\ln(g_t^w)$ – though the interpretation of these shocks has changed a little. In the basic version, all four processes were components of the output process. Here, in the full version, these are components of technology, TFP from now on. Thus, all four components of the TFP follow the same process as their counterpart in the basic version. The parameters governing these processes also remain exactly the same.

An additional source of change in output growth is stochastic world interest rate. The equation above shows that a 1% increase in interest rate decreases the borrower output by $(\psi^c - 1) \cdot \eta^c$ percent.

State Space Form

With output growth of the borrowing country as the observable, the measurement equation of country c can be written in state space form using 4 global state-variables – z_t^w, z_{t-1}^w, $\ln(g_t^w/g_{ss}^w)$, $\ln(g_{t-1}^w/g_{ss}^w)$ – and 4 country-specific state-variables – z_t^c, z_{t-1}^c, $\ln(g_t^c/g_{ss}^c)$, $\ln(g_{t-1}^c/g_{ss}^c)$.

$$\Delta y_t^c = \ln(g_{ss}^c) + \alpha_X^c \ln(g_{ss}^w) - (\psi^c - 1)\eta^c \Delta r_t^* + \psi^c \Delta z_t^c + \psi^c \alpha_z^c \Delta z_t^w + \psi^c \ln(g_t^c/g_{ss}^c)$$
$$+ \psi^c \alpha_X^c \ln(g_t^w/g_{ss}^w) - (\psi^c - 1)\ln(g_{t-1}^c/g_{ss}^c) - (\psi^c - 1)\alpha_X^c \ln(g_{t-1}^w/g_{ss}^w)$$

Again, the presence of global shocks in the output of all the countries makes it necessary for the combined state-space form to contain all the countries stacked one over the other for every time period t. The measurement equation of this combined state-space form at time t will look like:

$$\Delta y_t = W_t + V \cdot \theta_t$$

The dimension of Δy_t is $(nc \times 1)$ (where nc is the total number of countries). W_t is not time invariant now as it depends on changes in world interest rate. The dimension of W_t is also $(nc \times 1)$. V is $(nc \times (4 * nc + 4))$ and it is still time invariant as before. The state variable θ_t is $((4 * nc + 4) \times 1)$. The evolution of state vector (transition equation) is represented as:

$$\theta_t = K \cdot \theta_{t-1} + \lambda_t$$

Section B.2 of appendix reproduces the state-space form and gives formulation of all the vectors and matrices related to the state-space form.

Estimation of Country Specific and Global Parameters

The dataset still consist of 19 defaulters from Latin America & the Caribbean plus 5 developed countries. Thus with 24 countries, I still have the same 146 parameters to estimate as the basic model. Additionally, the full model has ψ^c and η^c for all the countries to estimate. This takes the total number of parameters to 194.

Table 4: Bayesian Estimation Results from Full Model: Posterior means

Country	Posterior (Means)							
	ρ_z^c	ρ_g^c	σ_z^c	σ_g^c	ψ^c	η^c	α_z^c	α_X^c
Argentina	0.2813	0.6431	0.0134	0.0141	2.0832	0.3924	0.0196	0.0029
Belize	0.4934	0.7748	0.0028	0.0138	2.5386	0.3669	0.0041	0.0017
Bolivia	0.9477	0.2448	0.0136	0.0036	2.3502	0.0713	0.0086	-0.0003
Brazil	0.2023	0.8617	0.0025	0.0122	2.2738	0.6329	0.0078	0.0065
Chile	0.9267	0.6321	0.0110	0.0210	1.7075	0.1645	0.0126	0.0082
Costa Rica	0.2902	0.5339	0.0039	0.0069	2.3393	0.9032	0.0073	0.0092
Dominican Republic	0.3735	0.5430	0.0135	0.0235	1.7342	0.8289	0.0078	0.0089
Ecuador	0.4392	0.7825	0.0084	0.0142	1.4405	0.7039	0.0092	0.0020
Guatemala	0.7671	0.7034	0.0025	0.0083	1.7201	0.6772	0.0054	0.0090
Guyana	0.3798	0.6713	0.0037	0.0125	2.9785	0.3414	0.0159	-0.0035
Honduras	0.4223	0.6674	0.0043	0.0096	2.0775	0.5282	0.0050	0.0103
Mexico	0.7295	0.7787	0.0057	0.0104	2.0862	0.2603	0.0105	0.0107
Nicaragua	0.9303	0.7011	0.0152	0.0254	2.0281	0.7145	0.0073	-0.0019
Panama	0.5375	0.8314	0.0039	0.0141	2.5912	0.4966	0.0129	-0.0016
Paraguay	0.5385	0.6997	0.0047	0.0162	1.8303	0.1220	0.0121	0.0081
Peru	0.4378	0.7591	0.0051	0.0205	1.8000	0.2680	0.0239	-0.0020
Trinidad and Tobago	0.1823	0.8532	0.0040	0.0177	1.9957	0.0632	0.0054	0.0079
Uruguay	0.9247	0.7466	0.0088	0.0117	1.7514	0.7631	0.0261	0.0001
Venezuela, RB	0.8535	0.5335	0.0174	0.0105	2.0829	0.3363	0.0129	0.0080

Posterior means for σ_z^w and σ_g^w are 0.8897 and 0.7555 respectively

The countries included in the estimation process are 24. 19 defaulting countries from Latin America & Caribbean and 5 non-defaulting developed countries. Parameter estimates are reported only for 19 Latin America & Caribbean countries.

The estimation procedure and the dataset remains the same here as in the basic version. I keep the normalization assumptions: $\sigma_z^w = 1$, $\sigma_g^w = 1$; and $\alpha_z^{VEN} > 0$, $\alpha_g^{VEN} > 0$ for identification. The prior distributions are shown in the Table A6 of the appendix. The priors are again uniform and are same as the basic model. For ψ and η, I take the help of the equation from the model. In the model, ψ depends on the labor share as well as the Frisch elasticity of labor supply and thus, I assume a uniform prior from 1.01 to 4.[18] In the model, η is a fraction of wage bill needed in advance. I use a uniform prior between 0.0001 and 0.9999 for η.

Table 4 reports the mean of posterior distribution from a Markov chain of 2 million draws. Table A8 in the appendix reports the mean and the standard deviation both. Table 4 shows that both the global shocks to transitory and permanent component of TFP are very persistent, $\rho_z^w = 0.89$ and $\rho_g^w = 0.76$. Some negative values of α_X^c shows that global shock led some countries to see an increased growth when other countries saw a growth slowdown. The values of ψ^c are close to 2 rather than the prior mean 2.5. The values of ψ^c close to 2 suggest Frisch elasticity value to be 2.5 is we assume that labor share is 0.7. This value of Frisch elasticity means $\omega = 1.4$ which is close to what other paper use in the macroeconomics literature.[19] Values of η^c vary from 0.07 to 0.90 showing that, for example, Bolivia needed 7% wage bills in advance whereas Costa Rica needed 90%.

Table A8 shows that the persistence parameters are much more precisely estimated in the full model than the basic model. Small standard deviations for α values show that α is more precisely estimated compared to the basic version and the table also shows that α values are statistically different from 0 for many countries. Standard deviation values for ψ^c and η^c show that those values are also precisely estimated. The standard deviations are much smaller for ψ^c than for η^c.

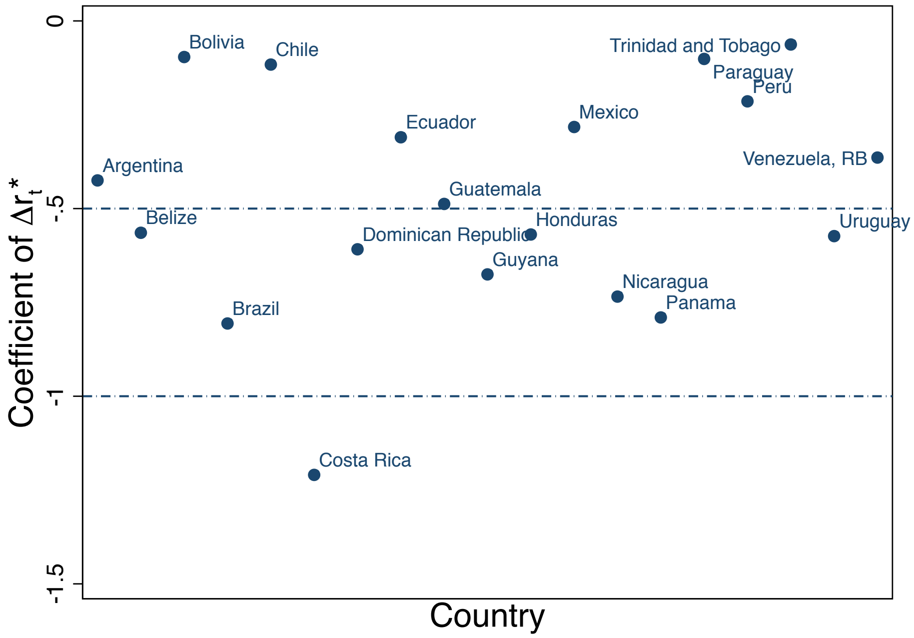
Given the values of ψ^c and η^c, I calculate the value of $-(\psi^c - 1) \cdot \eta^c$, which is the coefficient of Δr^* in the output growth equation of the full version. This values shows the change in output that a borrower experiences if the world interest rate changes by 1%. Figure 3 shows the magnitude of this coefficient for different countries. Most of the countries lie around the -0.5 line which means that a 1% increase in world interest rate would cause the output of countries like Argentina, Guatemala, Belize, Uruguay etc to go down by almost 0.5%. Countries like Brazil, Panama and Nicaragua show higher sensitivity in output with respect to changes in the borrowing rate while countries like Mexico, Chile and Peru show lower sensitivity.

Using the mean values from the posterior estimates of all the parameters, I smooth out

[18] The expression for Frisch elasticity of labor supply from the model is $1/(\omega - 1)$. Given that a lot of microeconometric estimates of Frisch elasticity lie between 0.3 and 0.5 while a lot of macroeconomists use an estimate between 2 and 4, I calculate ω to vary from 1.2 to 6 given that I allow the Frisch elasticity to vary from 0.2 to 5. Additionally, α_L is labor share which is considered to be close to 0.7 and I assume it to vary from 0.3 to 0.9. This way, the value of $\psi = \omega/(\omega - \alpha_L)$ varies from 1.0526 to 4 which is a subset of the interval of my prior on ψ.

[19] Mendoza (1991) for example uses $\omega = 1.455$ which gives a Frisch elasticity value of 2.2.

Figure 3: Coefficient of Δr^* from the output growth: $-(\psi^c - 1) \cdot \eta^c$



the latent global shocks and the country-specific shocks that different countries face by the Kalman smoothing algorithm, exactly the same way as in the basic version. Figure A6 of the appendix shows the time-series of global transitory and permanent components of output. The top panel shows a big negative transitory shock that started in early 1980s and reach a minimum in 1990. Another big negative transitory shock was around early 2000s. The bottom panel shows multiple permanent shocks but the ones with the biggest impact are observed during 1975s, 1980s and at the onset of the great recession. In the basic version, it was the transitory shock to output that hit during the great recession but here, it is the permanent global shock. Like before, both the time series are scaled to the parameters of Argentina.

The time series obtained using the Kalman smoothing is used in the model section when I simulate the optimal debt and default decision for all the countries.

5 Empirical Analysis

The Kalman smoothed time-series of shocks – country-specific shocks for every country and global shocks – obtained from the estimation part are used to perform some preliminary tests. Moreover, using a regression framework, I ask if countries faced different shocks during clustered defaults vis-$\grave{a}$-vis idiosyncratic defaults.

I start by examining transitory and permanent shocks around idiosyncratic and clustered default episodes.[20] I then decompose these shocks into their global and country-specific counterparts to investigate their individual contribution toward idiosyncratic and clustered defaults events. In the next step, I perform a regression analysis to uncover if global shocks play a substantial role in explaining clustered defaults. I start with logistic regression exercise and predict the probability of default events. I then test if including global shocks as an explanatory variable *does* increase the predicted probability for the default events.

In order to utilize the data on defaults by 92 countries and 146 defaults from 1975 to 2014, I perform Bayesian estimation on biggest possible subset of countries. I impose the condition that countries must have a continuous time series of output starting no later than 1960. This along with data availability of other regressors leaves 49 countries and 87 default episodes to analyze. To check robustness, and to work on an even larger set of countries, I also perform HP-filtering on the output data which requires output from 1975 and not 1960. This results in 58 countries and 99 defaults episodes to be analyzed.

5.1 Global and Country-specific Shocks around Default Episodes

I use aggregate transitory and permanent shocks, along with their global and country-specific counterparts around different default episodes. This way I aim to distinguish whether a representative clustered default episode faced different shocks, in terms of nature and severity, than a representative idiosyncratic default episode. I use median values of shocks across default episodes, clustered or idiosyncratic or both type, to get the representative default of respective category. The results remain robust to using mean values.

The basic version of the output process of a country, say c, has already been given as:

$$Y_t^c = e^{z_t^c + \alpha_z^c z_t^w} \cdot X_t^c (X_t^w)^{\alpha_X^c}$$

Using this output specification in a multi-country setup, Bayesian estimation provided the parameters governing the global shock processes – z^w, $\ln(g^w)$ – and the country-specific shock processes – z^c, $\log(g^c/g^c_{ss})$. The estimation also provides the parameter with which

[20]The time series of all the four components of output that we use has a nice property. Since the only observable in the estimation is output growth of countries, the estimation process is completely independent of the default data. Additionally, adding developed countries that have never defaulted in the estimation process makes sure that the estimated global shocks are not contaminated by the presence of default events. Thus, adding these additional developed countries gets rid of the reverse causality problem. A negative shock to some global component of output will not be a result of output decline of a set of countries in response to default.

global shocks affect the output of country c: α_z^c and α_X^c. Thus, I construct the aggregate transitory and permanent shocks – $z^c + \alpha_z^c z^w$, $\ln(g^c/g_{ss}^c) + \alpha_X^c \ln(g^w)$ – for the output of every country. I then decompose these aggregate transitory and permanent shocks into global and country-specific components to study their movements near the default episodes.

The first row of Figure 4 shows median values for the aggregate transitory component of the GDP and growth in the aggregate permanent component of the GDP near default episodes. The three lines in each figure show median values across all default episodes, across clustered default episodes and across idiosyncratic default episodes. The figure suggests that during clustered defaults, even though the countries were doing much better 1 year before the crisis and 2 years before the crisis, they underwent a steep drop in output as they approach the year of default. This drop is much more severe in the case of the transitory component of the GDP. For idiosyncratic defaults, half of the time the countries were doing poorly even 2 years before the default, and they gradually do worse as the countries approach the default year. The next two rows decompose the permanent and transitory shocks into global and idiosyncratic components.

Figure 4 further suggests that the big negative transitory shock that a lot of borrowers observed during clustered default episodes is mainly driven by the global shock to the transitory component of output rather than by idiosyncratic shock. On the other hand, the permanent shock, which is slightly more pronounced in the clustered default episodes is coming mainly from country-specific shocks.

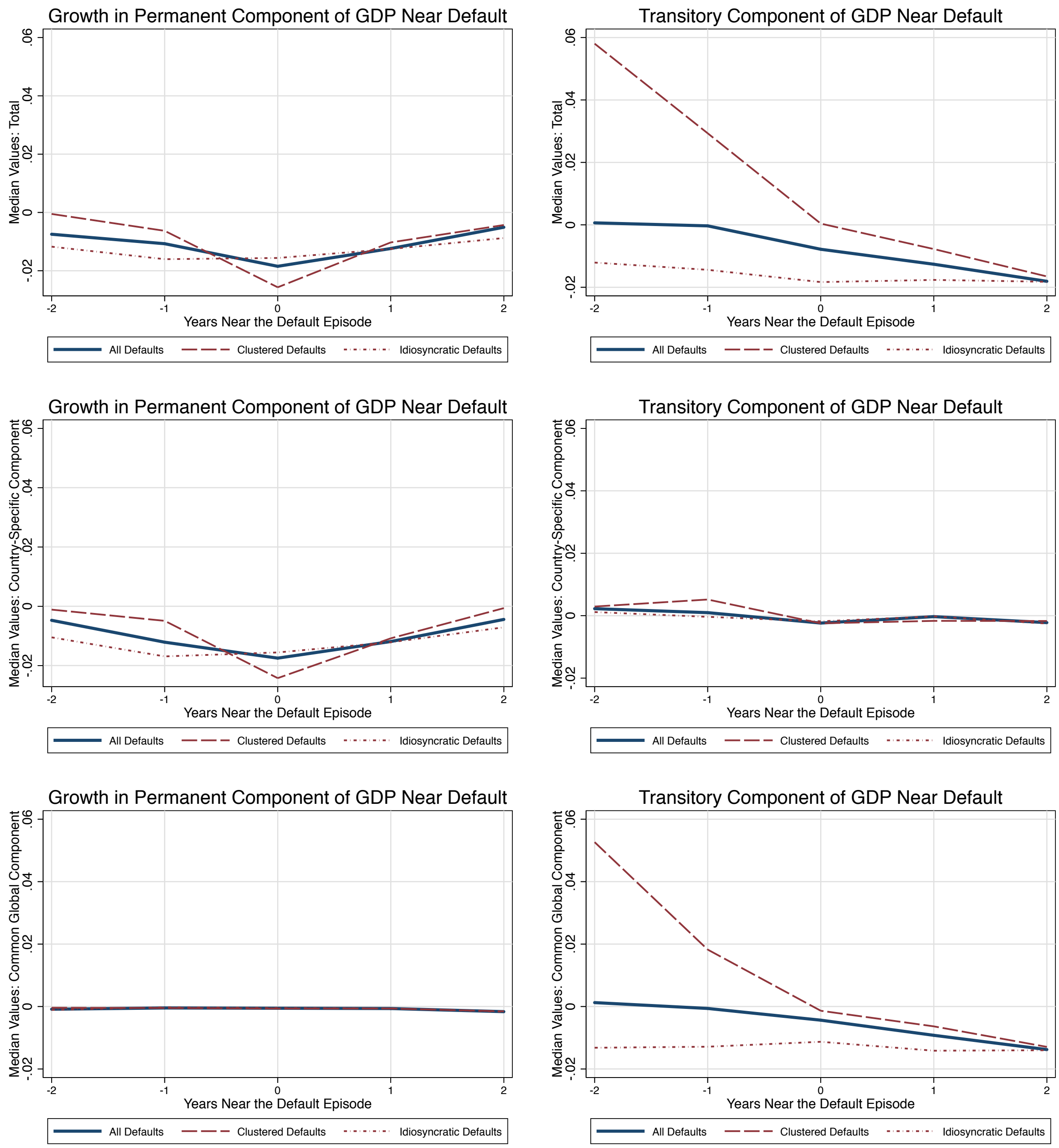
Another thing to note in Figure 4 is that the decline in the transitory component of the GDP is much more severe than the actual magnitude of the transitory component, even in the year of default. Growth in the permanent component, on the other hand, is negatively affected for most of the defaulters.

The results on permanent and transitory shocks presented in Figure 4 remain robust to HP-filtering the output series of individual countries to get the cycle and the trend growth. [21]

The last global variable I look at is the world real interest rate. Since the period of 1981-1983 is the period of higher than usual interest rates as well as a period of clustered defaults, figure 5 shows that clustered defaults were accompanied by higher risk free interest rates while idiosyncratic defaults happened at an median risk free rate of around 4%.

[21] Since the HP filter cannot give us a global shock from country outputs, we use cyclical and trend shocks to world output as a proxy for global shock. For idiosyncratic shock, we use cyclical and trend components for every country individually.

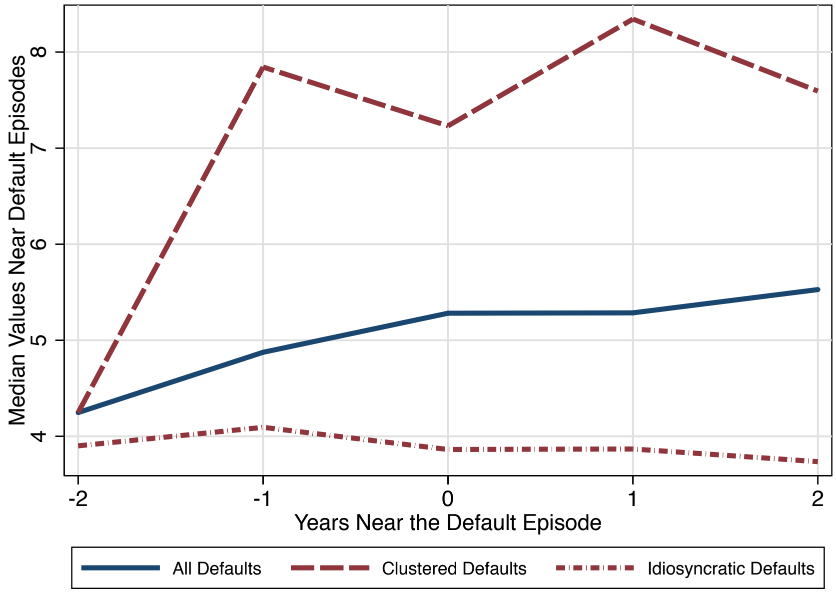
Figure 4: Transitory and Permanent Components of Output Near Default



Notes: (1) 0 depicts the crisis year. -1 and -2 depict 1 and 2 years before the crisis, while 1 and 2 depict 1 and 2 years after the crisis. (2) The diagram is based on components of the output process obtained from estimation using data from 19 defaulting countries and 5 developed countries.

The left panels plot growth rate in the permanent component of GDP. It starts with the total growth rate of the permanent component – $\log(g_t^c/g_{ss}^c) + \alpha_X^c \log(g_t^w/g_{ss}^w)$ – in the first row, then decomposes its country-specific and global parts – $\log(g_t^c/g_{ss}^c)$ and $\alpha_X^c \log(g_t^w/g_{ss}^w)$ – respectively. The right panels plot the transitory component of GDP. It starts with the total transitory component – $z_t^c + \alpha_z^c z_t^w$ – in the first row, then decomposes its country-specific and global parts – z_t^c and $\alpha_z^c z_t^w$ – respectively.

Figure 5: World Interest Rate Near Default



Note: 0 depicts the crisis year. -1 and -2 depict 1 and 2 years before the crisis while 1 and 2 depict 1 and 2 years after the crisis.

5.2 Empirical Specification

A preliminary look at the country-specific and global shocks shows that countries involved in clustered defaults faced negative global transitory shocks to output as well as a hike in world interest rate. In this subsection I incorporate country-specific and global shocks in a regression framework to tackle the problem in a formal setting. I predict the probability of default for all observed default events using two specifications: one with only country-specific explanatory variables and the other with both country-specific and global explanatory variables. Predicting the default probability for default events and comparing them across the two specifications tells us the marginal role that global variables play in influencing sovereign defaults. The empirical exercise shows that clustered default episodes can be explained significantly better when the specification includes global variables. Idiosyncratic defaults, on the other hand, are not influenced by the presence of global variables in the specification, and the predicted probability of default remains the same across both specifications.

Since the canonical work on sovereign default attributes defaults to the high indebtedness of the borrower or to the negative output shock to the borrowing countries, it is natural to assume the same for idiosyncratic defaults. Clustered defaults, however, due to the nature of being concentrated around a small window, suggest a role of worsening global fundaments. Thus, I test whether global shocks play a differential role in clustered defaults vis-à-vis idiosyncratic defaults. Since the default decision is a 0/1 variable, I use a logistic regression framework, similar to Kaminsky and Vega-Garcia (2016), to explain default decisions.

The logistic regression framework attributes the default status of a country to a set of factors including negative output shocks to countries. Negative output shocks to a borrowing country is expected to keep the borrowing country in default status. This gives rise to a probable reverse causality concern. Not only low output in the country might lead the borrower to default and keep it in default status for a long time, but also, a default in the borrowing country might cause its output to remain low for the foreseeable future.[22] Thus, to get ride of reverse causality issue, it is reasonable to drop data for the borrower for a few years after the country's default. I remove data subsequent to a default for all years in which the borrower remains in default status and has difficulty accessing world financial markets.[23]

The two regression specifications are as follows:

Specification 1:

$$D_{c,t} = \beta X_{c,t} + \mu_c + e_{c,t}$$

Specification 2:

$$D_{c,t} = \beta X_{c,t} + \gamma X_{w,t} + \mu_c + e_{c,t}$$

In both specifications, the default dummy, $D_{c,t}$, is the dependent variable. It takes a value of 1 in the year the country defaulted or is in default status, and 0 otherwise. Since I remove data points in which the country is in default status after the country has defaulted because of reverse causality concerns, I have $D_{c,t} = 1$ only in the period of default. Both specifications include country fixed effects to account for unobserved country-specific differences. In terms of explanatory variables, both specifications have country-specific variables, $X_{c,t}$. Only the second specification has global variables, $X_{w,t}$, which is the difference between two specifications.

As most of the literature emphasizes, output shocks to borrowers are one of the most important criteria that explain sovereign defaults. To capture these output shocks, I use the same components of output that I received from the estimation exercise: country-specific and global shocks to transitory and permanent component of output.

Besides the transitory and permanent components of country-specific output shocks, the next country-specific explanatory variable used here is the borrower's net foreign asset position as a percent of GDP.[24] This ratio of net foreign assets to GDP measures the indebtedness

[22]The output can remain low after default for several reasons: reduced borrowing due to restricted access to financial markets, trade restrictions, increased unemployment due to devaluation policies post default, etc.

[23]This data is available from Uribe and Schmitt-Grohé (2017).

[24]The series on net foreign assets as a percentage of GDP is available only to 2011, and thus the paper uses the series on government debt as a fraction of GDP for robustness checks. The series on government debt is available for recent years and is highly correlated with the series on net foreign assets as a fraction

of the borrower. For global explanatory variables, the first one I use is real interest at the disposal of investors. I construct the data on the world real interest rates by using the 5-year Treasury constant maturity rate and adding a market risk spread to it. This spread is constructed by using Moody's seasoned BAA-rated corporate bonds and Moody's seasoned AAA-rated corporate bonds. I further adjust the interest rate for inflation by using expectations for one-year-ahead annual average inflation measured by the GDP price index. The next global variables are the transitory and permanent components of global shocks to output. Lastly, I use inflation-adjusted oil prices to control for the investment surge hypothesis of defaults. The hypothesis, largely related to the Latin American defaults of 1982, suggests that a decrease in oil prices can cause defaults. The mechanism starts with a rise in oil prices that causes an investment surge in developing countries by oil-rich countries. This leads to over indebtedness, which results in default when oil prices plummet and investments dry up. Since this channel is expected to work through the debt level of a country, which the specification has already controlled for, it is unclear whether controlling for oil prices will matter. Oil price fluctuations can also lead to global shocks in output through the supply channel. To this end, global output shocks, both transitory and permanent, are already added as explanatory variables, and again it becomes unclear whether controlling for oil prices will matter.

Before I move on to the results and compare the two specifications, I check whether the regression coefficients concur with common beliefs in the literature about the effect of different explanatory variables on a default decision: First, negative output shocks lead to defaults. Second, high indebtedness or a low new foreign asset position as a percentage of GDP lead to default. Third, high world real interest rates lead investors to pull money out of borrowing countries, making it harder for the borrower to get new loans and service existing debt. This eventually leads the borrower to default. Lastly, plummeting oil prices cause investments to dry up in developing countries, which eventually results in default.

Coming back to specifications, the two regression specifications suggest two different hypotheses. The first specification suggests that a country's decision to default depends, for the most part, on the borrowing country itself. A priori, we can expect that adverse output shocks to the borrowing country and too much debt for the borrowing country as a percentage of GDP can lead the country into default. The second specification also takes global variables into account. These global variables proxy shocks to global fundamentals that affect all borrowers together. In this specification, therefore, we expect worsening global fundamentals to cause default. Thus, the specification says that the default decisions depends not only on borrower-specific variables, but global variables as well.

of GDP (correlation coefficient of -0.84).

Each regression specification and the corresponding hypothesis seems to fit one category of defaults better than the other. The first specification which attributes defaults only to country-specific explanatory variables, seem to fit idiosyncratic defaults more. Since these defaults happen in solitude compared to clustered defaults in which default by a country is accompanied by defaults in multiple other countries, it is plausible that global shocks do not make a significant difference in leading countries to idiosyncratic defaults. Clustered default episodes, on the other hand, usually face worsening global fundamentals around the same time countries decide to default. Thus, it seems appropriate to assume that clustered default episodes are a much better fit for the specification and the hypothesis that includes global shocks as explanatory variables.

Since each specification and the corresponding hypothesis fits one category of default better than the other, we reformulate the hypotheses according to the default category. For idiosyncratic default episodes, we hypothesize that going from specification 1 to specification 2 does not make a big difference in predicting the idiosyncratic defaults, on an average. In other words, adding global shocks to a specification that already has country-specific shocks does not make a significant difference in predicting idiosyncratic defaults compared to a specification with only country-specific shocks. For clustered defaults, we hypothesize that specification 2 significantly improves the predictive power of clustered defaults over specification 1.

To test the reformulated hypotheses, we run both specifications. Once we have the regression coefficients, we predict the probability of default for each of the specifications. We then look at the probability of default for 87 default events in our sample. If the hypothesis is true, we expect the Specification 1 to be better – or both the specifications to be almost the same – for the idiosyncratic default events in our sample. Additionally, the Specification 2 must yield significantly higher default probabilities for the clustered-default events in our sample. Mathematically,

$$\hat{Pr}(\hat{D}_{c,t} = 1 | D_{c,t} = 1, S_1) \geq \hat{Pr}(\hat{D}_{c,t} = 1 | D_{c,t} = 1, S_2)$$

$$\hat{Pr}(\hat{D}_{c,t} = 1 | D_{c,t} = 1, S_1) < \hat{Pr}(\hat{D}_{c,t} = 1 | D_{c,t} = 1, S_2)$$

5.3 Results

As emphasized in the literature, the results confirm that the debt level in a country as a percentage of GDP and country-specific shocks to the output of the borrowing economy are both good predictors of default. Additionally, real interest rate shocks and global shocks to transitory component of the GDP are also good predictors of default events. For idiosyncratic defaults, the results show that the predicted probability of default events conditional on default is almost the same for both specifications. For clustered defaults, however, the predicted probability of default conditional on default events is more than twice as high in Specification 2 than in Specification 1. Thus, global shocks make a big difference in leading countries to default when it comes to clustered default events.

5.3.1 Specification with Country-specific Variables

Table 5: Logistic Regression Results

	Specification 1		Specification 2	
	Coefficient	$\frac{d(Prob)}{dx_i}\sigma_{x_i}$	Coefficient	$\frac{d(Prob)}{dx_i}\sigma_{x_i}$
Country-Specific Variables				
(NFA as a % of GDP)$_t^c$	-0.008***	-0.0897	-0.007**	-0.0680
$\log(g_t^c/g_{ss}^c)$	-19.39***	-0.1325	-17.51***	-0.0949
$\Delta z_{t,t-2}^c$	-1.672	-0.0142	-2.774	-0.0188
Global Variables				
(Real interest rate in US)$_t$			0.282***	0.0960
$\log(g_t^w/g_{ss}^w)$			21.99	0.0215
$\Delta z_{t,t-2}^w$			-20.06**	-0.0554
(Inflation Adjusted Oil Prices)$_t$			-0.006	-0.0271
Country Fixed Effects	Yes		Yes	
N	1220		1220	
pseudo R^2	0.100		0.218	

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Motivated by set of stylized facts discussed in section 5.1, I choose 2-year change in the country-specific and global shocks to transitory component of output as explanatory variables. The results are reported in table 5. I also show that the results are robust to choosing the level of country-specific and global shocks to transitory component of output rather than 2-year changes. The results with levels instead of changes are reported in Table A2 of the appendix. Table 5 shows that although all three country-specific explanatory variables have expected signs, only debt level and the country-specific shocks to trend component of the output are statistically significant in predicting the default decision of the borrowing country.

Columns 2 and 4 of table 5 report the regression coefficients. Since the empirical specification uses logistic regression, the coefficient estimates have a lesser quantitative appeal beyond the signs. For this reason, I also report marginal effects of changing an explanatory variable on probability of default in column 3 and 5 of Table 5. For example, Column 3 shows that 1 standard deviation decrease in net foreign asset as a fraction of output increases the probability of default by 0.09. Similarly, 1 standard deviation decrease in the growth rate from its average increases the probability of default by 0.13. A drop in 2-year difference of the country-specific shock to the transitory component of output does decrease the probability of default but the magnitude of this change in not significantly different from 0.

5.3.2 Specification with Country-specific and Global Variables

Column 4 of table 5 shows the results of specification 2. As they were in specification 1, the coefficients related to all the country-specific variables remain very similar in terms of magnitude and their effect on default decision of the country. Among global variables, only the real interest rate in US and the 2-year change in transitory component of real output make significant effect on the probability of default.

Column 5 of table 5 shows that a 1 standard deviation increase in US interest rate causes the default probability to go up by almost 0.10. This is in line with the belief that when credit becomes expensive, countries find it harder to roll over the existing debt and they tend to default more often. It also supports the commonly held belief that increased risk free rates have substantial negative impact on default decisions. Negative global shock to transitory component of the output also increase the default probability, as expected. A 1 standard deviation decrease in $\Delta z^{w}_{t,t-2}$ causes default probability to go up 0.06. The sign on the coefficient of global permanent growth shock to output is surprising, even if it is statistically indistinguishable from 0. This is also evident from bottom left panel of figure 4. Clearly, during and near the default episodes, the fluctuations in global component of permanent growth are non-existent compared to other output shocks. The coefficient on oil prices, though not statistically significant, confirms our expectation that oil price decrease leads to decreased lending in emerging countries. The decreased lending causes difficulties in repayment of the interest and the principal of existing debt. This leads to more frequent defaults. For oil exporting developing economies, a decrease in oil price leads to decrease in export revenues and the output which can also lead to default.

While considering the changes in probability when we change an explanatory variable by 1 standard deviation, there might be a concern whether we can interpret the change in probability by directly multiplying the marginal effect and standard deviation together. This is because of the shape of logit function. It shows very small changes in probability with increases in the explanatory variable both at low and high values of the explanatory variable. This concern is addressed in figure A3 in the appendix. This figure shows that our estimates in column 5 of table 5 are close estimates of the actual marginal changes.

With summary stats of the explanatory variables in table A1 and marginal effects of these explanatory variables in figure A3 of the appendix, we can go back to look at the contributions of different global shocks in leading countries to clustered defaults vis-à-vis idiosyncratic defaults. As shown in figure 5, median real interest rate during a default is higher for clustered default episodes by almost 2.5% compared to the median for idiosyncratic defaults. This shows that all other variables remaining the same, real interest rate alone can account for a rise in probability of default by 0.12. Figure 4 shows that 2-year change in country-specific shock to transitory component of output is -0.05 for clustered default episodes while it is close to 0 for idiosyncratic episodes. Thus, ceteris paribus, global shocks increase the probability of default during clustered default episodes by 0.15 compared to probability of default during idiosyncratic default episodes. Both of these observations suggest a substantial role for global shocks when it comes to clustered defaults. The same global shocks, on the other hand, do not seem to play any major role in increasing the probability of default for idiosyncratic default episodes. In the next section I test this hypothesis more formally.

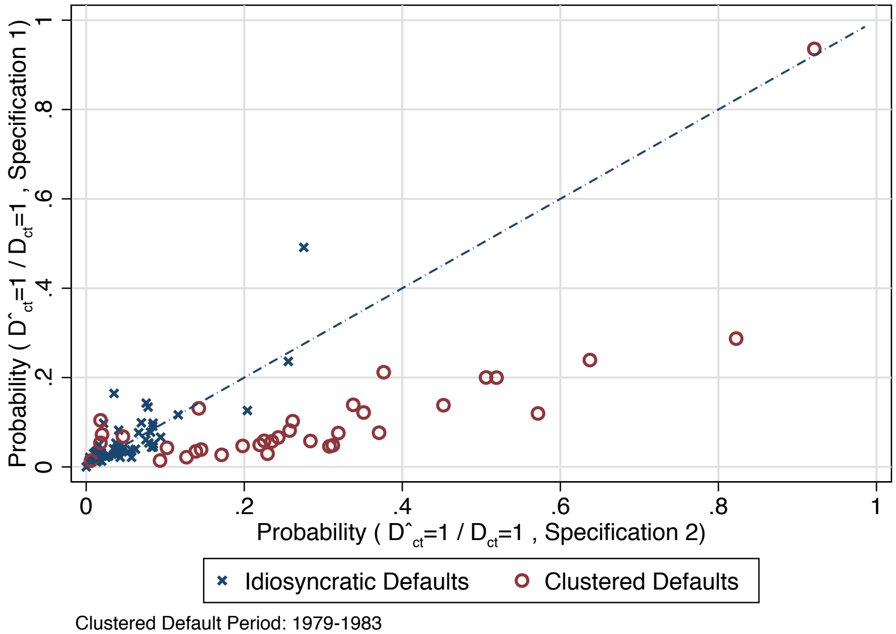
5.3.3 Comparing Specifications: Clustered and Idiosyncratic Defaults

Given the predicted probability of defaults from both the specifications, the paper compares the two specifications across clustered and idiosyncratic defaults. Figure 6 shows predicted probabilities for all the default events. On y-axis we have the predicted probabilities from specification 1 and x-axis measures the same from specification 2. Additionally there is a 45-degree line to see if the predicted probabilities are the same in both the specifications or they are systematically higher in one of the specifications than the other. A default episode on the right of the 45-degree line means that Specification 2 beats Specification 1 at predicting that particular default while opposite means it is Specification 1 that wins. The figure also attaches different markers to idiosyncratic and clustered defaults.

In an ideal scenario, since the predicted probabilities are conditional on the respective country defaulting in the data, all these predicted values should be close to 1. Figure 6 shows that this is clearly not the case. Predicted probabilities are substantially lower than 1. This signifies inability of the explanatory variables in predicting default which is also evident from low pseudo-R^2 values in Table 5. Even though the values of predicted probabilities are low, Figure 6 shows that clustered defaults lie systemically towards the right of 45-degree line while idiosyncratic defaults events look evenly distributed on both side of the 45-degree line. This shows that both the specifications do equally well in predicting idiosyncratic defaults and hence global variables play virtually no role in predicting the idiosyncratic defaults. Contrarily, adding global variables increase the probability of default for most of the defaults that happened during the cluster of 1979-1983.

Table 6 presents the results of figure 6 more formally. It shows that on an average,

Figure 6: Predicted probabilities of default using Specification 1 and Specification 2



predicted probability of default for idiosyncratic defaults is 0.063 when we use Specification 1. Including global variables along with country-specific variables to predict idiosyncratic defaults doesn't make much of a difference. Average predicted probability of default in Specification 2 is 0.056. Predicted probabilities for clustered defaults differ a lot based on the specification we use. On an average, the predicted probability of clustered default is 0.115 in Specification 1. This average is higher than the one in idiosyncratic defaults with either of the specifications. This tells us that country-specific fundamentals were also poor during the clustered default episode of 1979-1983. With Specification 2 the average predicted probability of clustered default events jumps to 0.285. The difference of mean t-stat is negative and significant at 0.1%. This is close to 150% jump just by adding global variables in the specification. Thus, even though country fundamentals were poor during the clustered default period, global fundamentals were much worse. This shows that including global variables in the specification makes a big difference in explaining the probability of default for clustered default episodes but it does not make any difference in explaining idiosyncratic default episodes. This signals toward a role of worsening global fundamentals in leading multiple countries to default during the clustered default period of 1979-1983.

The results in figure 6 and table 6 are robust to the alternate specification where we use the levels of country specific and global shock to transitory component of output instead of their 2-year changes. This can be seen in figure A4 and table A3 from the appendix. The

Table 6: Predicted Probability of Default for Default Episodes

		Average(Predicted probability of default conditional on default)		t-stat
Default Type	N0.	Specification 1	Specification 2	$\hat{P}(D=1\|S_1) = \hat{P}(D=1\|S_2)$
Idiosyncratic Default	52	0.0634	0.0561	1.2078
Clustered Default	35	0.1146	0.2853	-7.0813

results are also robust to using government debt data instead of net foreign assets and to using HP filtered data on output of countries instead of Kalman smoothed data from the estimation exercise. However, these results are not attached in the appendix in order to avoid repetition.

The last issue of concern is predicted probabilities of default conditional of non default. First, since the default probabilities conditional on countries defaulting in non-clustered period are already low, the default probabilities conditional on non-default in the same period must be even lower. Second, in the clustered period, probabilities of default conditional of countries defaulting has been high. Conditional on countries not defaulting, the probability of default should not be high. It should not be the case that bad global fundamentals are predicting high probabilities of default even in cases when countries did not default.

Table 7: Predicted Probability of Default for Non-Default Episodes

		Average(Predicted probability of default conditional on no default)		t-stat
Period	N0.	Specification 1	Specification 2	$\hat{P}(D=1\|S_1) = \hat{P}(D=1\|S_2)$
Non Clustered Default Period	968	0.0360	0.0254	11.0789
Clustered Default Period	165	0.0354	0.0635	-5.2251

Table 7 shows that in non clustered period, the predicted probability of default conditional of no default is almost half the probabilities conditional on default in the same period. This shows that on an average, in relatively calmer times, predicted probability of default for non default cases is smaller in magnitude. To address the concern that poor global fundaments in the clustered period might make the predicted default probabilities to be sky high even conditional of non default cases, I focus on row 2 of table 7. It shows that the predicted probabilities conditional on no default are very small compared to the predicted probabilities conditional on default during the clustered default period. Table A4 in the appendix shows that both the results are robust to change in explanatory variables.

6 Model

The empirical section highlights two important facts: (1) Global variables are mainly responsible for leading countries to default during clustered defaults episodes but they do not play any role during idiosyncratic defaults, and (2) Among global shocks, it is the shocks to transitory component of the output and the shocks to interest rate that seem to be driving clustered defaults. In this section, the paper builds a model incorporating global shocks to transitory and permanent components of output as well as world interest rate shocks. The presence of three global shocks enable the model to assess the causal impact of these global shocks on default decision through the lens of a sovereign default model.

The model is built on a standard Eaton-Gersovitz framework. I start with a baseline version of the model where the output has country-specific transitory and permanent components as well as global transitory and permanent components. At the start of the baseline version, world interest rate is assumed to be constant in order to asses the relative impact of different output shocks on default decisions. I then make world interest rate stochastic so that changes in interest rate can influence the default decision through changes in price of debt. This enables the model to assess the contribution of world interest rate shocks, through the *debt-pricing channel,* relative to the contribution of output shocks. Lastly, I build an extended version of the model which incorporates financial frictions in the form of working-capital constraints at the firm level. The presence of financial frictions enables changes in world interest rate to effect the default decision through endogenous changes in output of borrowing countries. The extended version assesses the contribution of world interest rate shocks, through the *debt-pricing channel* and the *endogenous output channel*, relative to the contribution of output shocks.

In spite of the fact that the shocks are estimated independently of the model or of default data, once fed into the model, they reproduce the clustered default of 1982, providing a joint validation of the model and the estimated driving forces. The model predicts that it is the global shocks to the transitory component of output that are most important in leading countries to default in clusters. Interest rate shocks are also important and can lead multiple countries to default but contrary to what is commonly believed, the Volcker interest-rate hike was not a determinant factor of the 1982 developing country debt crisis.

6.1 Eaton-Gersovitz Setup

This section outlines the model of sovereign default. The model is based on the the standard Eaton-Gersovitz framework and is closely related to the work done by Aguiar and Gopinath (2006)and Arellano (2008). The model features incomplete markets due to the presence of single period non state-contingent debt that countries use to borrow. In the absence of commitment device, the countries can optimally chose to default on the outstanding debt in certain periods.

The framework of the model is built on the assumption of exogenous but stochastic output realizations. I also start with the same assumption in the baseline model but relax the assumption by having endogenous labor choice in the model which determines the level of output in the extended version. Since the extended version encapsulates the baseline version to a high degree, I explain the extended version of the model here and present equations related to the baseline version in the Section C.1 of the appendix.

The agents involved in the full model are similar to most of the papers in the literature – households, firms, a benevolent planner or a government, and a foreign lender. Neither households nor the firms are involved in borrowing from rest of the world. The government issues debt and transfers the proceeds to households every period. Households make consumption and labor supply decision. Firms produce the final good by employing labor but the amount of labor that can be demanded at a given wage is constrained by the working capital requirement. To finance the working capital, firms get intra-period loans from the foreign lender and they do not default on these loans.[25] Government however does not have a commitment device and is free to default, if optimal. Foreign lenders are assumed to be risk neutral.

Households

The household gets utility from consuming the final good and gets disutility from supplying labor. The utility function takes the form of GHH preferences from Greenwood et al. (1988) and is concave, strictly increasing and twice differentiable.

$$U(C_t, L_t^s) = \left[\frac{\left(C_t - \frac{\Gamma_{t-1}(L_t^s)^\omega}{\omega} \right)^{1-\gamma}}{1-\gamma} \right]$$

where γ represents the Arrow-Pratt measure of relative risk aversion, $1/(\omega - 1)$ is the Frisch elasticity of labor supply and Γ is the scaling factor which is used to de-trend the variables that grow over time. Since consumption grows over time but labor is stationary, the scaling

[25]The rate on these loans is the rate on US treasury plus the spread between BAA-rated Moody's 5 year bonds and AAA-rated Moody's 5 year bonds. This rate captures the increase in risk aversion among the investors that is not coming from country risk. This rate is then discounted by expected inflation data from the survey of professional forecasters. This rate might not reflect the rate at which the firms in the borrowing country get loans at but as long as the changes in these rates are consistent or even proportional, results remain the same.

factor is multiplied with the labor term to make it grow over time.

Every period households earn wage income along with the profits that they earn from the firms they own. They can not borrow from rest of the world but the government borrows and households get transfer from the government. The household budget constraint is therefore given as:

$$C_t = w_t L_t^s + \Pi_t^f + T_t \tag{1}$$

Taking wages, profits and transfers as given, households maximize the present discounted value of their lifetime utility subject to the budget constraint. Households make consumption and labor supply decision at every period t. Since households are not directly involved in borrowing and holding debt, there is no inter-temporal decision that households make. Setting up the household problem:

$$\mathscr{L} = \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(C_t - \frac{\Gamma_{t-1}(L_t^s)^\omega}{\omega} \right)^{1-\gamma}}{1-\gamma} + \lambda_t \Gamma_{t-1}^{-\gamma} \left\{ w_t L_t^s + \Pi_t^f + T_t - C_t \right\} \right]$$

The first order conditions with respect to labor and consumption can be reduced to:

$$\Gamma_{t-1}(L_t^s)^{\omega-1} = w_t \tag{2}$$

which is the labor supply equation. The left hand side shows the marginal rate of substitution between leisure and consumption while the right hand side is wages. Intuitively, if I forego one unit of leisure i.e. I supply one more unit of labor, I get a disutility of $\left[\left(C_t - \frac{\Gamma_{t-1}(L_t^s)^\omega}{\omega} \right)^{-\gamma} \Gamma_{t-1}(L_t^s)^{\omega-1} \right]$. On the other hand, an additional unit of labor provides wages of w_t which can go on to increase consumption. This will lead to an increase in utility by $\left[w_t \left(C_t - \frac{\Gamma_{t-1}(L_t^s)^\omega}{\omega} \right)^{-\gamma} \right]$. At the margin the household must be indifferent between supplying an additional unit of labor and not supplying it. Thus, equating the marginal utility from increase consumption and marginal disutility from increase labor, we get Equation 2.

The budget constraint, Equation 1, and the first order condition, Equation 2, constitute the household equilibrium conditions.

Firms

Firms are the final good producer that demand labor to produce output at every time period t.[26] In order to hire labor and produce output, firms need working capital in advance.

[26]We abstain from dealing with capital but an assumption of constant capital stock will also work. The reason is to abstain from capital accumulation dynamics.

The working capital requirement forces the firms to have an a fraction of total labor wage payments in advance. To finance the working capital, firms take intra-period loan from foreign lenders.[27] Firms do not default on these intra-period loans and therefore make a payment of $(1 + r_t^*)M_t$ at the end of the period t for a loan of M_t that they received at the start of period t.

Assuming the technology in country c at time t is $A_t^c = e^{z_t^c + \alpha_z^c z_t^w} X_t^c (X_t^w)^{\alpha_X^z}$, the output of country c at time t can be written as:

$$Y_t^c = A_t^c (L_t^{d,c})^{\alpha_L^c}$$

where $L_t^{d,c}$ represents the labor demand of country c at time t and α_L^c is the labor share in output. Henceforth, I will omit the country superscript c for convenience. Given the output, the profit of the firm at time t is given as:

$$\Pi_t^f = (1 - \phi(z_t, z_t^w, g_t, g_t^w)) \cdot A_t (L_t^d)^{\alpha_L} - w_t L_t^d + M_t - (1 + r_t^*) M_t \tag{3}$$

where ϕ is a function of technology shocks and it takes a value of 0 in normal times. When a country defaults, the country suffers a dip in TFP and the function ϕ governs this decrease in TFP.

Like households, firms do not borrow via the single period debt from foreign lenders. Additionally, assuming away from capital leaves spares us from the inter-temporal dynamics of capital accumulation. Thus, firms, like households, do not have any inter-temporal decision to make. Firms maximize the present discounted value of lifetime profit subject to the period by period working-capital constraint.

$$\max \sum_{t=0}^{\infty} \beta^t \lambda_t \left[(1 - \phi_t(\cdot)) A_t (L_t^d)^{\alpha_L} - w_t L_t^d + M_t - (1 + r_t^*) M_t \right]$$

subject to

$$M_t \geq \eta w_t L_t^d$$

Setting up the firm problem:

$$\mathscr{L} = \sum_{t=0}^{\infty} \beta^t \lambda_t \left[(1 - \phi_t(\cdot)) A_t (L_t^d)^{\alpha_L} - w_t L_t^d + M_t - (1 + r_t^*) M_t + \xi_t \{ M_t - \eta w_t L_t^d \} \right]$$

[27] Alternatively, we can include banks in the model and assume that firms take this intra-period loans form the home country banks and banks have some endowment.

The first order conditions with respect to L_t^d and M_t are given as:

$$\alpha_L(1-\phi_t(\cdot))A_t(L_t^d)^{\alpha_L-1} = (1+\eta\xi_t)w_t$$

$$r_t^* = \xi_t$$

Since the two first order conditions can be condensed into one and given that working-capital constraint always binds, the firm equilibrium conditions will be given by the profit function and following two equations:

$$M_t = \eta w_t L_t^d \tag{4}$$

$$\alpha_L(1-\phi_t(\cdot))A_t(L_t^d)^{\alpha_L-1} = (1+\eta r_t^*)w_t \tag{5}$$

Equation 5 captures the essence of working-capital constraint. The marginal benefit from having an extra worker is still the marginal product of labor but the marginal cost of having an extra labor is higher with working-capital constraints. The firm not only pays the wage for an extra worker, it also pays the interest on the intra-period loan that they needed in order to hire an extra worker. This intra-period loan is is a fraction of wage of that additional labor and hence the total interest on that intra period loan is $\eta r_t^* w_t$. This is the extra term in the firm first order condition.

Government

The aim of benevolent social planner or the government is to maximize the utility of the households. Unlike households and firms, the government has access to foreign credit markets and can borrow by issuing single period non state-contingent debt at a price q_t. The government transfers its proceeds from the borrowing to the households as a lump sum transfer. Additionally, the government repays the outstanding debt.

Repayment of the outstanding debt is costly, specially when the price of new debt is low, as the repayment of old debt requires to be coming out of either the output or new borrowings. Lower price of new debt would cause the total value of new borrowing to be low. Thus, there is a possibility that benefits of not repaying debt might me high even at the cost of not borrowing at all. In cases like these, the government might find it optimal to default in some scenarios. When the government does default on it's debt, it not only loses access to the credit markets but it also suffers an additional output loss because productivity plunges in the country. From the next period on, the government can rejoin the market with a fixed probability λ and a debt level of 0. With probability $(1-\lambda)$, the government stays in the state where there is no access to credit.

Since there is a possibility that the government may find short term gain of not repaying higher than the benefit of having continued access to the financial markets and being able to smooth consumption, it defaults in some states of the world. Depending on the probability of these states arriving, the lender may not receive full repayment and thus the lending is not risk free. The lenders factor this possibility of default by the government into the price of debt q_t.

If the government chooses not to default and it repays its debt, it can choose a new debt level d_{t+1} to be repaid in the next period. In this case, the amount borrowed, net of repayments, is transferred by the government to the household.

$$T_t = q_t d_{t+1} - d_t \tag{6}$$

When the government decides to default, there is no additional borrowing and government transfer is 0.

The presence of debt makes the government optimization an inter-temporal problem. Due to the presence of this inter-temporal element in the optimization problem, most of the papers in the literature use recursive dynamic programing to solve the government's optimization. The first step of solving the problem is to identify the state-variables that effect the total value of flow utility received by the households in a period. The value function for a particular period depends on 4 set of state-variables: (1) output shocks in the period, (2) world interest rate in the period, (3) debt level the country enters the period with, and (4) whether the country started the period in good standing or bad, $f_t = \{0, 1\}$.

A country starts a period with good standing, $f_t = 0$, if it has access to credit markets. In this case, the government can decide to repay the debt and have continued access next period, $f_{t+1} = 0$, or it can decide to default today. If the government choses to default today, it won't have access to debt today but it won't have to repay the old debt either. Additionally, it can be redeemed with probability λ tomorrow. If it gets redeemed, the government starts the next period with 0 debt and it will have access to financial markets, $f_{t+1} = 0$. If the government stays in the bad standing with probability $(1 - \lambda)$, it will not have access to markets in the next period, $f_{t+1} = 1$.

The the continuation payoff i.e. value function when the agent doesn't default and continues to repay the debt, is given as:

$$V^C(d_t; z_t, z_t^w, X_t, X_t^w, r_t^*) = \max_{c_t, d_{t+1}} [u(c_t) + \beta E_{y,r}[V^G(d_{t+1}; z_{t+1}, z_{t+1}^w, X_{t+1}, X_{t+1}^w, r_{t+1}^*)] \tag{7}$$

subject to the equilibrium conditions of the households and the firms along with the government transfer condition. Here V^G represents the value function when the agent enters the period with good financial standing ($f = 0$).

If the agent enters a period in bad financial standing ($f_t = 1$) or decides to default ($F_t = 0$), it has a 0 debt to repay and the agent cannot borrow any new debt. Additionally, the agent faces an exogenous drop in TFP that reduces it's output and hence consumption even further. In the next period, the agent can re-enter the financial markets and be in good standing ($f_{t+1} = 0$) with probability λ.

$$\begin{aligned} V^B(z_t, z_t^w, X_t, X_t^w, r_t^*) = u(c_t^A) + \beta E_{y,r}\{\lambda V^G[(0; z_{t+1}, z_{t+1}^w, X_{t+1}, X_{t+1}^w, r_{t+1}^*) \\ + (1-\lambda) V^B(z_{t+1}, z_{t+1}^w, X_{t+1}, X_{t+1}^w, r_{t+1}^*)\} \end{aligned} \tag{8}$$

subject to the household and firm equilibrium conditions and that the transfer to households is now 0. In this case, the function ϕ, that governs output loss in default, will also be non-zero. The function ϕ and thus, the output loss in default depends on individual technology shocks.

If the agent is in good standing at the start of a particular period, he has two options: continue to repay the debt or default. If he continues to repay the debt, his flow utility for that period will be V^C. If the agent decides to default, his flow utility for that period will be V^B. The agent will choose the option that gives it a higher flow utility.

$$V^G(d_t; z_t, z_t^w, X_t, X_t^w, r_t^*) = \max\{V^C(d_t; z_t, z_t^w, X_t, X_t^w, r_t^*), V^B(z_t, z_t^w, X_t, X_t^w, r_t^*)\} \tag{9}$$

The default rule is therefore be given as:

$$F(d_t; z_t, z_t^w, X_t, X_t^w, r_t^*) = \begin{cases} 1 & \text{if } V^B(z_t, z_t^w, X_t, X_t^w, r_t^*) > V^C(d_t; z_t, z_t^w, X_t, X_t^w, r_t^*) \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

Lender

The last piece of the model is to explain the lender side. I assume a large number of risk neutral lenders. Risk free return is therefore adjusted for the probability of default to get rate of return on debt.

$$(1+r_t) \times Prob_{y,r}(V^C(d_{t+1}; z_{t+1}, z_{t+1}^w, X_{t+1}, X_{t+1}^w, r_{t+1}^*) > V^B(z_{t+1}, z_{t+1}^w, X_{t+1}, X_{t+1}^w, r_{t+1}^*)) = 1 + r_t^*$$

Given that the price of debt, $q_t = 1/(1+r_t)$, we have

$$q_t(d_{t+1}; z_t, z_t^w, X_t, X_t^w, r_t^*) = \frac{Prob_{y,r}(V_{t+1}^C > V_{t+1}^B)}{1 + r_t^*} \tag{11}$$

Equilibrium

In equilibrium, households, firms, government and the lender solve their respective optimization problem and the market for consumption good, labor, and debt clears (lenders choose price level of debt so that they get zero expected profits). Formally,

Definition 1. A sequence of variables: $\{C_t, L_t, M_t, \Pi_t^f, d_{t+1}, F, T_t, w_t, q_t\}$ and value functions $\{V_t^C, V_t^B, V_t^G\}$ constitute a recursive equilibrium given the initial debt level, d_t, TFP processes: $\{z_t, z_t^w, g_t, g_t^w\}$ and world real interest rate process, $\{r_t^*\}$, if:

1. Households choose $\{C, L_t^S\}$ to solve equations 1 and 2 given the wage rate w_t, government transfers T_t and profits from firms Π_t^f.

2. Firms choose $\{\Pi_t^f, M_t, L_t^D\}$ to solve equations 3, 4 and 5 given wage rate w_t and world real interest rate, r_t^*.

3. Wage rate, w_t, is such that labor market clears $L^S = L^D$ both in cases of default and continuation.

4. Government chooses $\{d_{t+1}, F_t, T_t\}$ to solve equations 6, 7, 8, 9 and 10 given the starting debt level, d_t, world real interest rate process, $\{r_t^*\}$, and the solutions to household and firm optimization problems.

5. Equilibrium bond price, q_t, is as in equation 11 and is such that households, firms and the government are solving their optimization problem and the risk neutral international lenders get zero expected profits, thereby clearing the debt market.

Autarkic Equilibrium

If the government enters the period in autarky, it does not have an optimization problem to solve. It makes no transfer to the households, $T_t = 0$, and it does not have a debt or default choice to make. Alternatively, if the government enters the period in good standing but finds that utility from defaulting is higher than utility from borrowing and repayment, it defaults. Again, the government does not have any choice variables once it decides to default. The transfers are, by default, $T_t = 0$, and there is no debt choice possible. Thus, in autarky, we have only firms and the households that will make their equilibrium choices.

First thing to note is that firms will face an output cost of default during autarky. Thus the output produced will go down depending on the state of the economy. Sine the output cost is convex in nature, the output loss in autarky will be higher when the economy is doing relatively better (relatively bigger shocks to different components of technology level in the economy). Firm's optimality conditions will therefore be given by:

$$\alpha_L(1-\phi_t(\cdot)) \cdot A_t(L_t^{Aut})^{\alpha_L-1} = (1+\eta r_t^*)w_t^{Aut}$$

which is the same condition that captures the effect of working-capital constraint on the cost of hiring an additional worker. The profit for the firm will be:

$$\Pi_t^{f,Aut} = (1-\phi_t(\cdot)) \cdot A_t(L_t^{Aut})^{\alpha_L} - w_t^{Aut}L_t^{Aut} - \eta r_t^* w_t^{Aut}L_t^{Aut}$$

where $\phi_t(\cdot) = \phi(z_t, z_t^w, g_t, g_t^w)$ is a function of states.

Households solve their first order conditions and supply labor such that:

$$\Gamma_{t-1}(L_t^{Aut})^{\omega-1} = w_t^{Aut}$$

Solving household and firm first order conditions will give closed form solutions to equilibrium quantity of labor and wage level in autarky as a function of state-variables and the parameters. These values are then used to get the values of equilibrium output and profit that households receive. These profits through the household budget constraint give the value of household consumption in autarky.

$$C_t^{Aut} = (1-\phi^{Aut}) \cdot A_t(L_t^{Aut})^{\alpha_L} - \eta r_t^* w_t^{Aut}L_t^{Aut}$$

Equilibrium with borrowing

Equilibrium with borrowing is the equilibrium in which the government gets to choose a debt level, d_{t+1}, in the current period. This can happen in two ways: If the government enters a period with good standing or if it enters the period in bad standing but gets to re-enter the market[28] , and finds it optimal to continue with repayment of debt in both the cases. In the former case, the government enters the period with a debt, d_t, to be repaid while in the later case, $d_t = 0$.

The first order conditions of the firm and the household provide us with a closed form

[28]An event that occurs with probability λ after entering the period in bad standing.

solution for equilibrium quantity of labor:

$$L_t = \left(\frac{\alpha_L A_t}{\Gamma_{t-1}(1+\eta r_t^*)} \right)^{\frac{1}{\omega - \alpha_L}}$$

which can be used to get the equilibrium wage rate from the household first order condition. Given the value of the wage rate, equilibrium quantity of labor, and an initial debt level, d_t, the government chooses a new debt level, d_{t+1}, so as to maximize it's continuation utility

$$V^C(d_t; z_t, z_t^w, g_t, g_t^w, r_t^*) = \max_{C_t, d_{t+1}} \{u(C_t, L_t) + \beta E_y[V^G(d_{t+1}; z_{t+1}, z_{t+1}^w, g_{t+1}, g_{t+1}^w, r_{t+1}^*)]\}$$

subject to:

$$C_t = A_t L_t^{\alpha_L} - \eta r_t^* \Gamma_{t-1} L_t^{\omega} + q_t(d_{t+1}; z_t, z_t^w, X_t, X_t^w, r_t^*) \cdot d_{t+1} - d_t$$

$$L_t = \left(\frac{\alpha_L A_t}{\Gamma_{t-1}(1+\eta r_t^*)} \right)^{\frac{1}{\omega - \alpha_L}}$$

$$q_t(d_{t+1}; z_t, z_t^w, X_t, X_t^w, r_t^*) = \frac{Prob_y(V_{t+1}^C > V_{t+1}^B)}{1 + r_t^*}$$

where V_{t+1}^B is the value function in autarky which can be solved using equations 8, 9 and the autarky equilibrium.

6.1.1 Model Calibration

The calibration is done for every version of the model separately. There are three version of the model: (1) baseline model with constant world interest rate, (2) baseline model with stochastic world interest rate, and (3) full model with stochastic world interest rate. I start with the basic version of the model with constant interest rate. Move on to the basic version where interest rate fluctuates and then finally to the full version of the model.

The parameters that we have in the model are related to the coefficient of relative risk aversion (γ), world interest rate (r^*), average yearly growth rate of the country (μ_g^c), parameter that governs the probability of rejoining the financial markets after default (λ), and the impatience parameter (β). Additionally, for the baseline version, I use the following loss function specification:[29]

[29] The output loss specification used in this paper is similar to the one used in Chatterjee and Eyigungor (2012) and also explained in Uribe and Schmitt-Grohé (2017) but I modify the specification to incorporate the feature from Aguiar et al. (2016) that loss function depends on individual shocks rather than total output.

$$\phi_t = \max\{0, a_1 + a_2 \cdot e^{z^c + \alpha_z^c z^w} g^c (g^w)^{\alpha_X^c}\}$$

which gives two more parameters (a_1, a_2). Since the expression in the ϕ_t function is same as the output of the country, total output net of output loss is effectively: $y - y \cdot \max\{a_1 + a_2 \cdot y\}$. This is similar to the quadratic output loss used in Chatterjee and Eyigungor (2012). The full version of the model will have an output loss function which looks a bit more complicated that the one used in the baseline version. This is due to the presence of interest rate shocks that also effect output of the country. Nonetheless, total output net of output loss in the full version will also boil down to the same expression. Hence, I have the same two two parameters (a_1, a_2), in the full version of the model.

Table 8: Calibrated Parameter Values

	Parameter Value	Example	Comments
γ	2	Standard	
r^*	3.67% pa	Standard	Average value from 1960 to 2014
μ_g^c	C-specific	1.025 for Arg	
λ	C-specific	0.095 for Arg	Matched 10.5 years in default on an average in 200 years
β	C-specific	0.83 for Arg	$\sim$ 0.95 quarterly; Matches defaults/100yr, NFA/Y
a_1	C-specific	-0.26 for Arg	Matches defaults/100yr, NFA/Y
a_2	C-specific	0.27 for Arg	Matches defaults/100yr, NFA/Y

Notes:

(1) Interest rate, r^*, is constant only in the first version of the baseline model

(2) The examples for the values of β, a_1, and a_2 correspond to the first version of the baseline model

The coefficient of relative risk aversion, γ, follows the existing literature. For example by Mendoza (1991), Arellano (2008) etc. assume γ to be equal to 2.

Since a unit of time in the model is an year instead of a quarter, the world interest rate, r∗, is calibrated to an average value between 1960 to 2014. This gives $r^* = 3.67\%$.

Steady state growth rate is different for different countries. Thus, to calibrate μ_g^c, I take the average yearly growth rate from the data spanning 1960 to 2014 for respective countries. For example, $g_{Arg}^{ss} = \mu_{Arg}^{ss} = 1.025$ corresponds to the average yearly growth rate of Argentina over 1960-2014.

In order to calibrate the probability of re-entry into the financial markets after a default, λ, I use data from Reinhart and Rogoff (2011b) and Uribe and Schmitt-Grohé (2017). Using an average 6 years for the exclusion period of Argentina, for example, I estimate the probability of re-entry to be 0.1667 for Argentina.

Three parameters remain: the impatience parameter, β, and parameters governing the output loss function, a_1 and a_2. All three parameters are country-specific and are calibrated to match the average number of defaults in 100 years as well as the average debt to GDP ratio when the country is in good financial standing.

6.1.2 Grid Size

I solve the model using finite state space method. I, therefore, start by detrending all the variables to make them stationary. Once the variables do not grow over time, the state-space needed for the iterations can remains fixed. The state variables in the detrended form of the model are: $\{z_t^c, z_t^w, g_t^c, g_t^w\}$. In the full version of the model, I also have $\{r_t^*\}$. The debt level, $\{d_t\}$, is an endogenous state variable.

I use 7 grid points for each of the output shocks taking the output grid size to 2,401 points in the baseline version of the model. Once the interest rate starts affecting output, through the *endogenous output channel*, in the full version of the model, the grid points on interest rate also contribute to output changes. Thus, an additional of 10 grid points for the interest rate take output grid size to 24,010 points. The number of grid points for the debt level is taken as 100. Thus, the total number of grid points on both, output and debt, seem large enough to alleviate the concerns of Hatchondo et al. (2010) about the inefficiency of the discrete state space technique.

The grid points are also used in the simulation exercise when I simulate the time-series of Kalman smoothed state-variables to pass through the model. I, therefore, analyze the grid points that I use to approximate the movements of the state-variables and examine if the grids can simulate the estimated global state-variables or not. Figure A7 in the appendix shows the detrended output for the basic model and for the full model. Each panel shows a version obtained from Kalman smoothing exercise as well as a version which is simulated through $7 \times 7 \times 7 \times 7$ grid points. It can be seen that the version simulated through the grid points matches the original Kalman smoothed version very well. Thus, the number of grid on output match the movement of detrended output very closely.

Simulation of state variables also requires simulating the interest rate through the grid points. For this purpose, I match the interest rate simulated through grid points and the actual movement of interest rate in the data to test if 10 grid points are sufficient to match the movements. Figure A8 shows that 10 grid points are sufficient for interest rate movements, simulated through grid points, to closely matches the actual movements in data.

6.1.3 Solution Algorithm

The presence of global shocks in the model makes global output shocks and interest rate shocks common across countries. Thus, the grid and the transition probability matrices of all the global shocks – 2 global output shocks and interest rate shocks – become common across all the countries. The grid for global output shocks are then scaled according to the parameters α_z^c and α_X^c for every country. Given these grids and transition probability matrices for the global shocks, the model is solved on country-by-country basis. For calibrating the parameters of the model, the moments are matched one country at a time. The remaining algorithm for model solution remains similar to the one available online from Uribe and Schmitt-Grohé (2017).

One more addition in the model, and hence the algorithm, is the introduction of firms and thus, labor. This addition doesn't come at a very big cost because equilibrium quantity of labor can be solved analytically, both when country wants to default and when it does not. Therefore, labor, with and without default costs, can be calculated based on the 5 exogenous state variables – 4 output shocks and interest rate. This gives a closed form solution for output as well as consumption based on the values of all 6 state variables, the sixth being initial debt level. Thus, current utility can be calculated using the utility function and it can this used to calculate the flow utilities. Once the flow utility is calculated, the remaining part of the algorithm becomes similar to the standard algorithm available from Uribe and Schmitt-Grohé (2017).

Once the model is solved, simulation is relatively straight forward as the time-series of global and country-specific shocks are already available for every country from Section 4. The time-series for these output shocks as well as the interest rate are available from 1960 to 2014. I assume the initial debt in 1960 to be 0.[30] Given the endogenous state – debt level in 1960 – and the exogenous states – four output shocks and the interest rate – every country chooses the default decision for 1961. Additionally, if the country chooses not to default in 1961, the country chooses the debt level. If the country choose to default in 1961, the initial debt level in 1961 automatically goes to 0. Thus, the optimal debt and default decision in 1961 proves a value for endogenous state variable in 1961, d_{1961}. Repeating this process till 2014, I get the time-series of default decision for all the countries. Aggregating across all the countries, I plot the percentage of countries defaulting in a rolling 5-year window for every year from 1960 to 2010.

[30]The data on government debt or NFA to GDP ratio is mostly available from 1970 onward. If we use this data and change the first year of simulation from 1960 to 1970, the results remain the same. This is because the initial debt level does not have much of an impact 2 or 3 years after the start of the period. Countries increase or decrease the debt level very quickly.

6.2 Model Performance

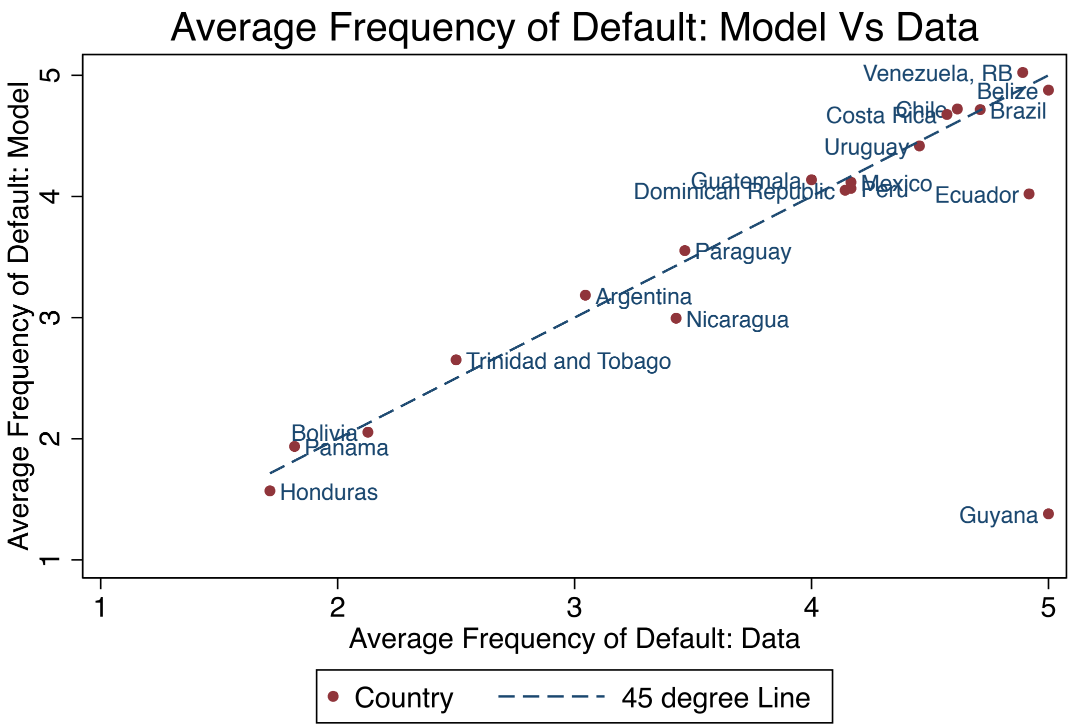
Before getting into the simulation of optimal debt and default decisions for different countries, I start with evaluating the performance of the model based on a set of moments in the data and their counterpart from the model. Some of these moments were targeted while calibrating the parameters of the model and hence, these moments are expected to have a good match in the model and as they are in the data. I also match some additional moments – mean and standard deviations of risk spread; correlation between spread and output; correlation between trade balance to output ratio and spread – that were not targeted by the model. I find that the model does extremely well in matching most of the moments from the data. This shows that apart from matching the clustered default, that I show later, the model exhibits remarkable performance in multiple other dimensions too.

Figure 7 shows the moments generated by the model and the moments observed in the data.[31] While performing the calibration, I choose the parameters related to discount rate, β, and the output loss function, a_1 and a_2, differently for every country in order to match average default frequency per 100 years as well as the average debt level as a percentage of output in the country. Since I target these moments, Figure 7 shows that the match of model generated moment and the moment from the data is very well except for the case of Guyana. In the case of Guyana, the data shows that Guyana, on an average during non-default periods, holds a negative net foreign asset amount equivalent of 144% of it's output after accounting for 90% of average haircut level. This huge level of debt coupled with a default rate of 5 times per 100 years is hard to match. The model tries to go as high as possible in terms of average debt as a percentage of output. This gets Guyana to hold a debt of around 60% of it's output but there is a sacrifice in terms of default frequency which drops to 1.4 defaults per 100 years.

The next two figures, Figure 8 and Figure 9, show the moments that were not targeted by the model. Figure 8 displays the mean and standard deviation of spreads. The mean and standard deviation data contains J.P. Morgan EMBI global stripped spreads and is available only for 10 of the 19 countries that we have in the paper. The top panel shows the average spread in non default episodes. The points the correspond to different countries are not as close to the 45-degree line as they were in the case of targeted moments. Most of the countries are still in the neighborhood of the 45-degree line except for Chile, Mexico and Peru. The standard deviation of spreads in non-default periods is matched much more closely. Other than Chile and Uruguay, other countries are in close proximity of the 45-degree line.

[31] Figure 7 and the subsequent figures compare moments from baseline version of the model with data.

Figure 7: Targeted Moments: Default Frequency and Average Debt in Non Default Periods



Average frequency of default is measured as defaults per 100 years

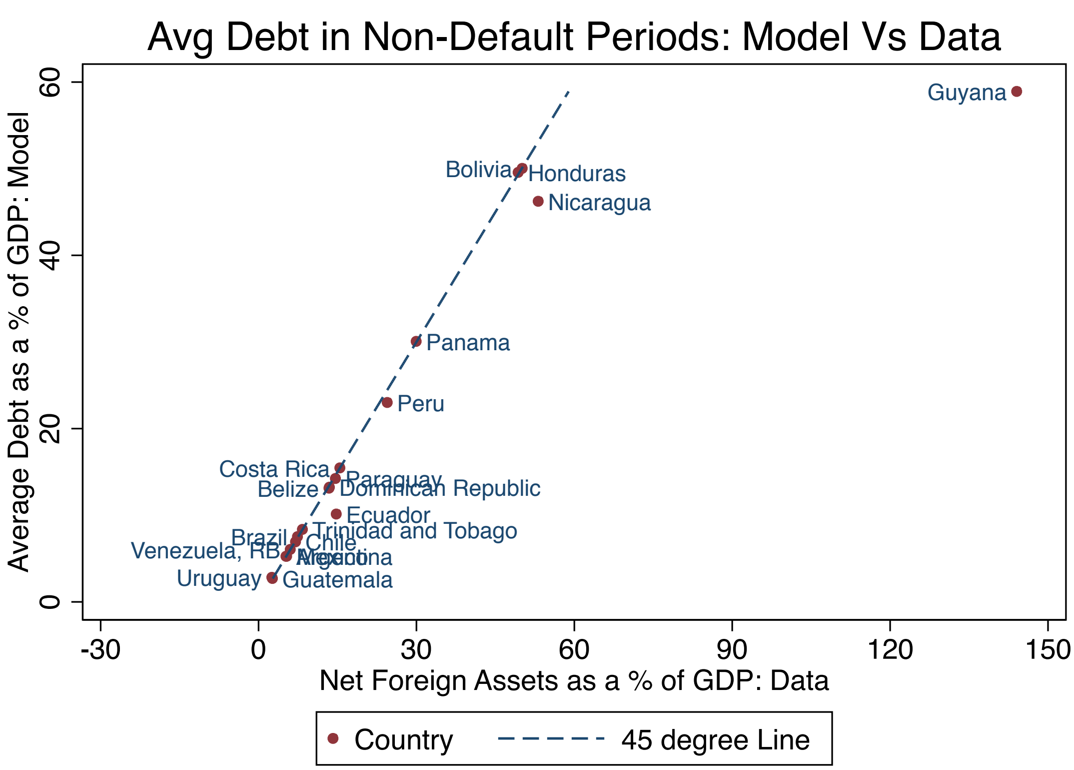


Figure 8: Non-Targeted Moments: First and Second Moments of Spread

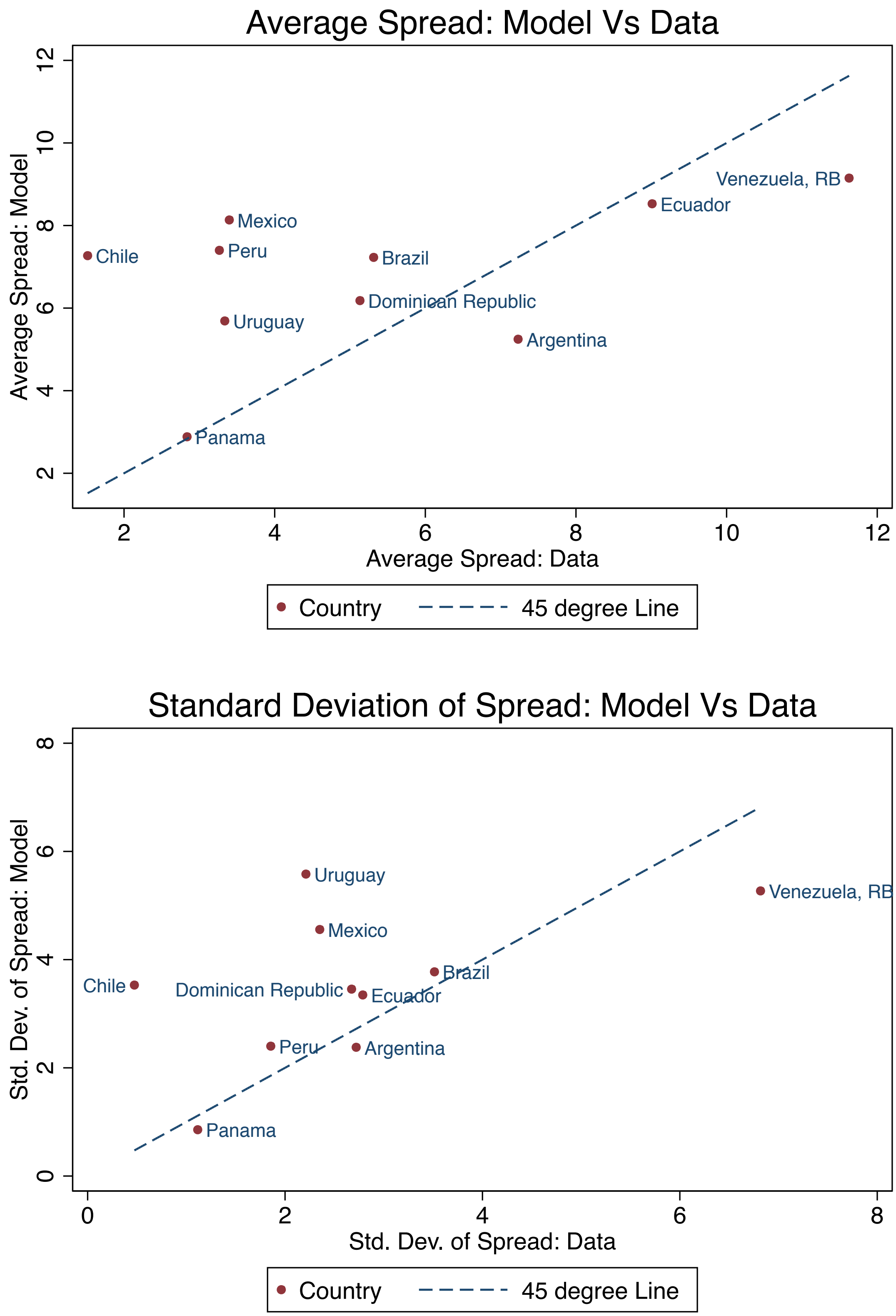
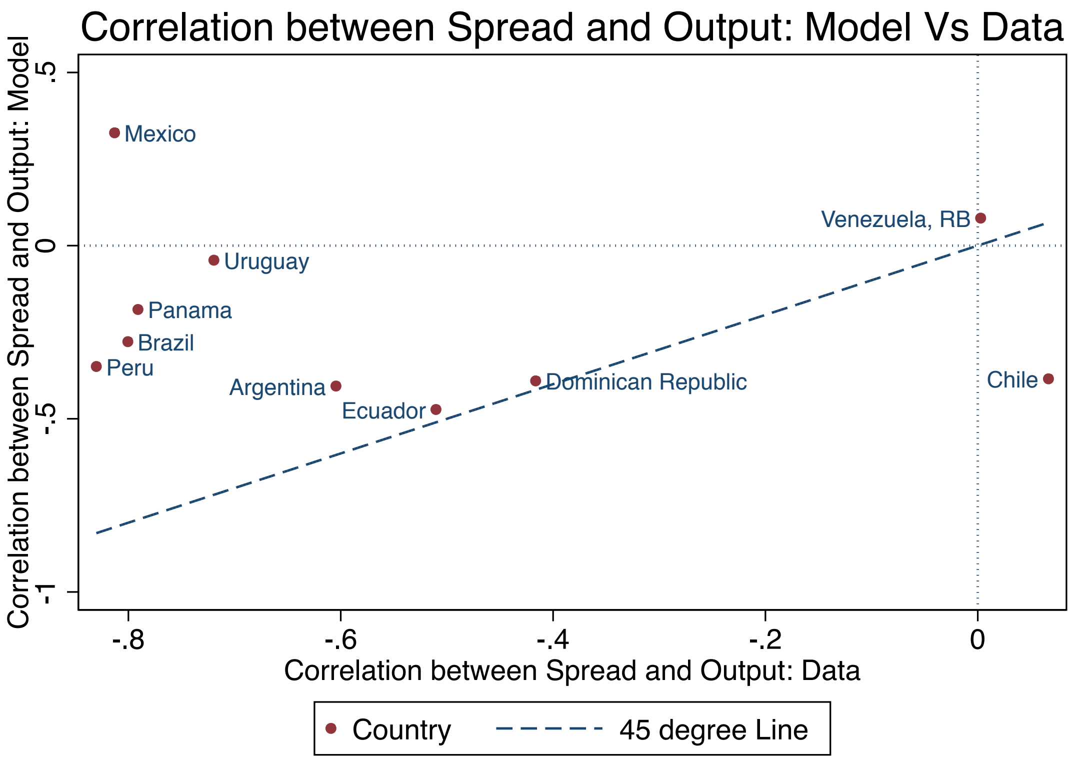
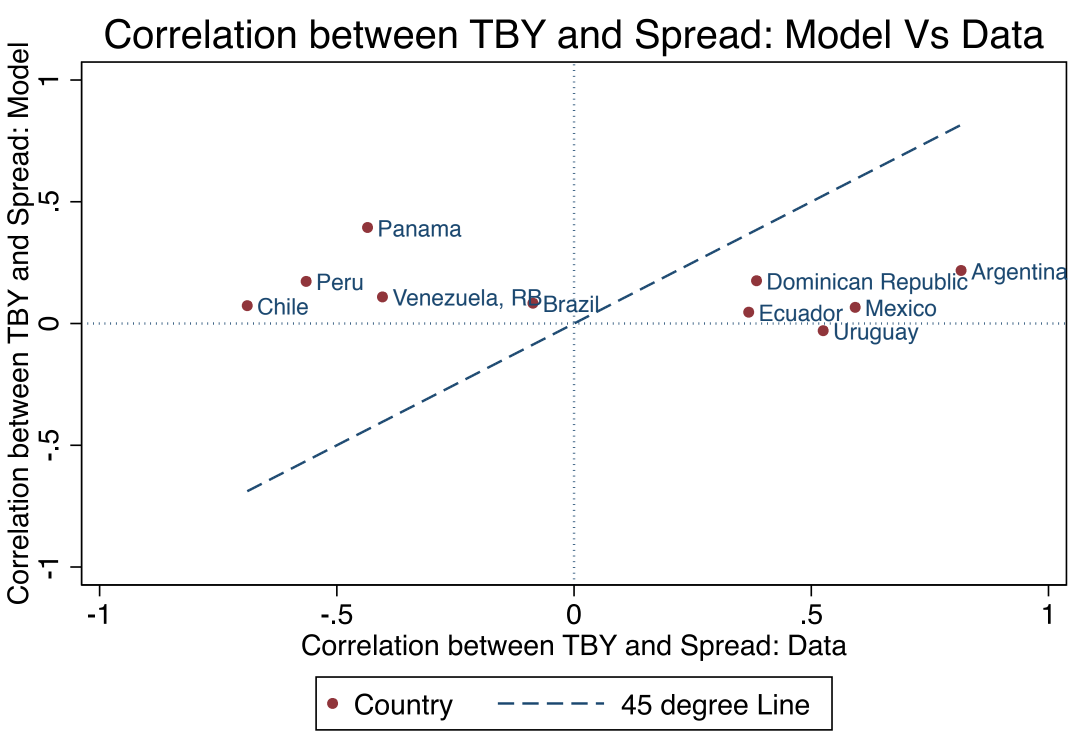


Figure 9: Non-Targeted Moments: Correlations with Spread





TBY represents trade balance to output ratio

The two remaining non targeted moments pertain to the correlation of spreads. Figure 9 shows that the model does well to explain the counter-cyclicality of country premium but the model doesn't do very good in terms of predicting the correlation between trade balance to output ratio and spread. Some of the countries show positive correlation between trade-balance to output ratio and spread while some portray negative correlation in the data. The model, on the other hand, displays small and positive correlation between trade balance to output ratio and spread.

6.3 Simulating the Defaults

For every country, the solution to the model provides the optimal decision – level of debt that the country chooses and if the country wants to default or not – for any value of the state variables (four output shocks, the interest rate shock and an initial level of debt). Thus, feeding the model with actual time-series of output shocks, estimated in Section 4, and interest rate shocks from 1960 to 2014, I get the default decision for every country and every year from 1960 to 2014. Aggregating these default decisions across all the countries from 1960 to 2010, I get the percentage of countries defaulting in a rolling 5-year window for every year from 1960 to 2010. Switching different shocks on and off and comparing the model predicted defaults with the data leads us to the two important results of the paper. The first one says that primary driver of clustered defaults is global shock to the transitory component of output. The second result says that Volcker interest-rate hike was not a decisive factor of the 1982 developing country debt crisis.

I use three version of the model here: (1) baseline model with constant world interest rate, (2) baseline model with stochastic world interest rate, and (3) full model with stochastic world interest rate. I start with the basic version of the model with constant interest rate. Move on to the basic version where interest rate fluctuates and then finally to the full version of the model.

These three models enable three comparisons. (1) Which output shocks are mainly responsible for clustered default episode of 1979-1983? (2) What is the marginal impact of introducing real interest rate fluctuations, that cause fluctuations in the price of debt, on default decision of countries? (3) What is the marginal impact of having a second channel, the effect of changes in interest rate on GDP of borrowers, captured by adding financial frictions in the model on GDP of borrowers and their default decisions? This way I can delineate if interest rate influences default decision more compared to output shocks. And if so, is it through the channel of debt pricing or the channel of endogenously effecting the output of emerging economies.

6.3.1 Baseline Model with Constant World Interest Rate

I start the time series of output shocks from 1960 onward. World interest rate is being kept constant at 3.66% and the initial level of debt in 1960 is assumed to be 0.[32] For all the subsequent periods, countries choose if it is optimal for them to default or not. This default choice is then aggregated across countries and I match percentage of countries defaulting in the model with its counterpart from the data.

Figure 10: Aggregated default decisions of all countries: Model with both country-specific shocks and global shocks vs Data

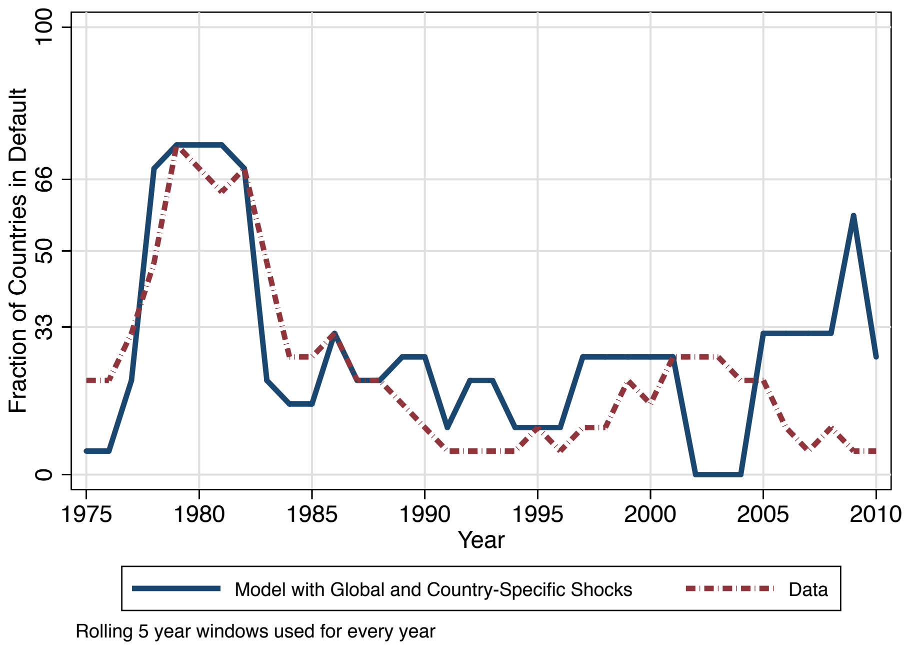


Figure 10 shows that the model predicts the clustered default of 1982 vey well. The model also shows a subsequent decline in defaults. A small surge of defaults that is observed in the data in early 2000s, is predicted a bit sooner in the model – in late 1990s. Additionally, the model also over-predicts the defaults at the time of the great recession. This over-prediction is not very surprising given that the model has not incorporated a bailout mechanism or a lender of last resort, which was how multiple countries avoided defaulting after the great recession.

The model succeeds in generating the cluster but it raises a next question: are global shocks essential in generating the cluster of 1982? To capture the effect of global shocks, I perform two exercises. First, I shut down all the global shocks by equating the global transitory shock to 0 and the growth rate in global permanent shock to be 1 for all the

[32]The results are robust to changes in initial level of debt.

periods from 1960 to 2014. In this exercise only country-specific shocks move the output of countries and hence default decisions are affected only by country-specific shocks. In the second exercise I do the opposite: I shut down all the country-specific shocks by equating the country-specific transitory shock to 0 and the growth rate in country-specific permanent shock to be equal to average growth rate of the country between 1960 and 2014. In this exercise only global shocks move the output of countries and hence default decisions are affected only by global shocks.

Figure 11: Aggregated default decisions of all countries: Model with only country-specific shocks vs model with only global shocks vs Data

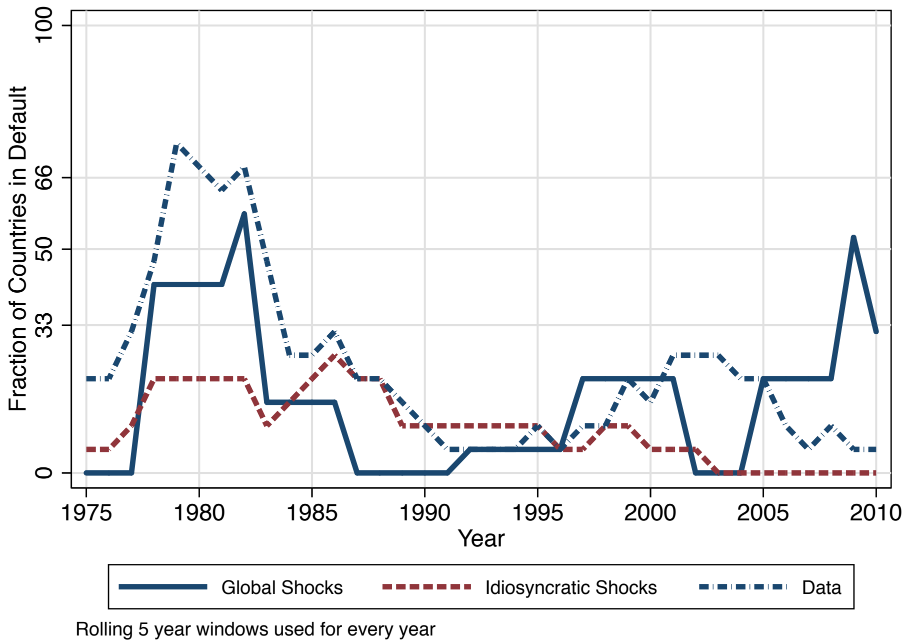


Figure 11 shows the results of the aforementioned two exercises and the observed defaults in the data. With only country-specific shocks the percentage of countries defaulting is very small and we do not observe a cluster. With global shocks, on the other hand, a cluster re-appears. The size of this cluster is smaller than the one observed in the data, portraying the importance of country-specific shocks at the same time.

The success of global variables in generating the cluster raises a new question: which global shock – global transitory shock or global permanent shock – matters more to generate the cluster of 1982? To capture the effect of individual global shocks, I perform two more exercises. First, I shut down only the global permanent shock. This is done by equating the growth rate in global permanent shock to 1 for all the period from 1960 to 2014. In this exercise country-specific shocks and global transitory shocks move the output of countries and hence default decisions are affected by all three. In the second exercise, I shut down only the global temporary shock. This is done by equating the global transitory shock to 0 for all the period from 1960 to 2014. Thus, country-specific shocks and global permanent shocks move the output of countries thereby effecting the default decision.

Figure 12: Aggregated default decisions of all countries: Model with country-specific shocks and transitory global shocks vs Model with country-specific shocks and permanent global shocks vs Data

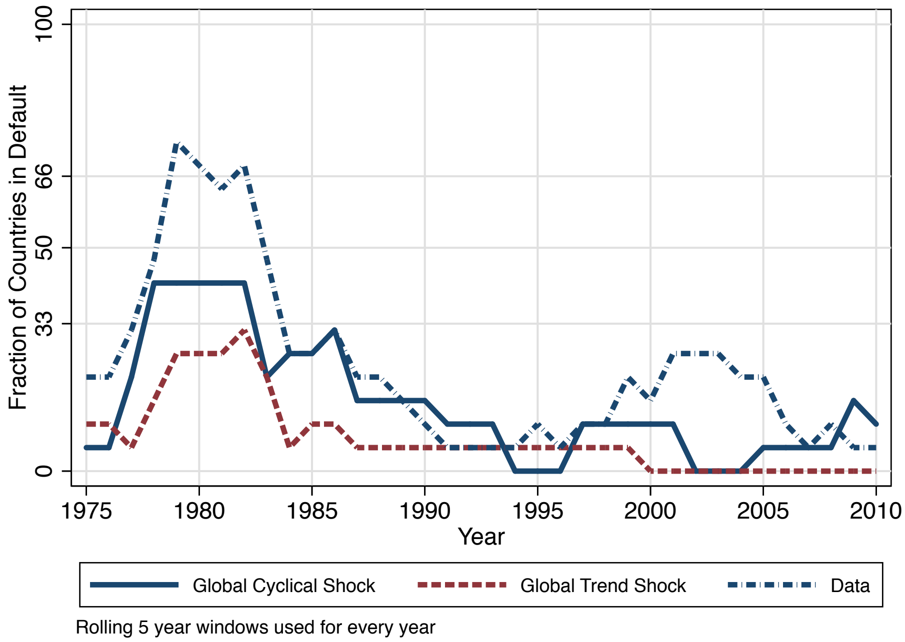


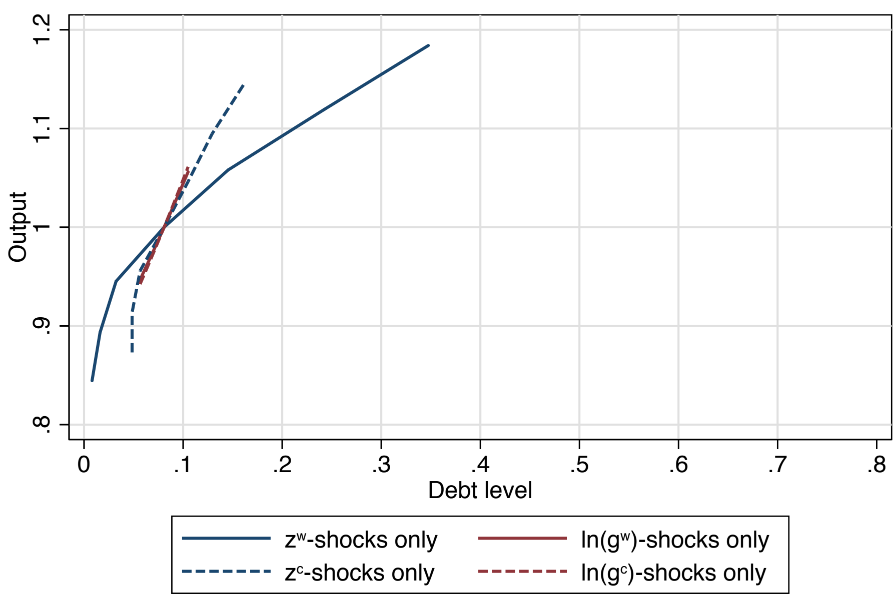
Figure 12 illustrates that global temporary shocks are relatively more important in replicating the cluster than global permanent shocks. Though the difference in the figure from two exercises is not as stark as in the previous case, the result that temporary shocks are more important than permanent shocks is surprising and counter-intuitive. The result is surprising because it contradicts a widely accepted result from Aguiar and Gopinath (2006) that it is the permanent shocks rather than temporary shocks that cause sovereign defaults. It therefore generates interest in understanding the mechanism through which transitory shocks cause relatively more defaults.

Role of Global Transitory Shocks in Causing Defaults

There are three elements in the model that make global transitory shocks important in causing clustered defaults. First, higher fluctuations in global transitory shocks. Second, and most important, convex output cost of default. Third, high persistence of global transitory shocks.

Though the impact of global shocks on different countries depend of the coefficients α, let us take the example of Argentina to start with. One standard deviation shock to global transitory component changes the detrended GDP of Argentina by 6%. One standard deviation shock to global permanent component changes the same by almost 2%. One standard deviation shocks in country-specific transitory and permanent components change the detrended GDP of Argentina by 5% and 2% respectively. Thus, for the case of Argentina, the global transitory shocks have biggest impact on the de-trended GDP. For countries other than Argentina, this might not be the case but, as I will show, global transitory shocks have biggest impact on default decisions even when compared to similar size of output shocks.

Figure 13: Default Region: Effect of Output Shocks on Default Decisions



Note: (1) Right side of the line represents the default region and left side represents non-default region. (2) Only one of z^w, z^c, $\ln(g^c)$ and $\ln(g^w)$ vary at a time. Others remain 0.

In order to show the importance of global transitory shocks for default decisions over similar size of output shocks, I go back to the model solution for the case of Argentina. Though the simulations from before show that global transitory shocks were most important in causing clustered default of 1982, looking at the indifference between value functions from the model provides more details about the mechanism. Figure 13 shows the default region for different shocks. Y-axis shows the output of Argentina in different scenarios while the X-axis represents the debt level in the country. Solid navy line corresponds to the case where the the economy is hit only by global transitory shocks. All other shocks are kept constant at their mean values. Given the shocks are only to global transitory component of output

(z^w-shocks), Y-axis shows the output in the presence of z^w-shocks only. The area on the right of this line the default region while the area on the left of it shows different combinations of z^w and d for which the country chooses not to default.

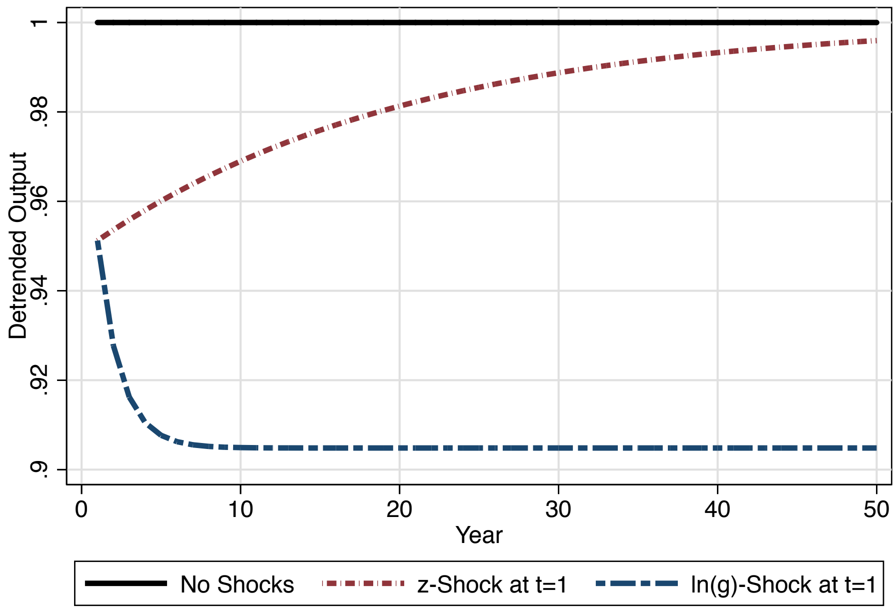
According to the solid navy line of Figure 13, after a few consecutive positive shocks to global transitory component, the country can accumulate a lot of debt and still be in the non default region. More specifically, with an output of 12% above the detrended mean in the presence of global transitory shocks, Argentina can accumulate a debt of up to 25% and can still remain in non-default region. At this point, if Argentina gets a 2 standard deviation negative shock to global transitory component, it will default unless Argentina holds a debt of less than 8% of GDP. Thus, accumulation of debt after positive z^w-shocks leads to a scenario where Argentine needs to deleverage a lot when it is hit by a negative z^w-shock. Thus, in some cases, Argentina might prefer to default than undergo a big deleveraging.

Moving on to remaining three shocks, the indifference lines between default and non-default regions are much more steep for other shocks. Thus, under these shocks, the amount of deleveraging needed to stay in non-default status is not big. Therefore, countries default much less under these shocks than under global transitory shocks. This is true even when the size of shocks are similar. Figure 13, therefore, raises two questions: (1) Why do transitory and permanent shocks behave differently? (2) Why do global and country-specific transitory shocks behave differently?

The answer to the first question lies in the convex default cost assumption. Figure 14 shows the detrended output of a country hit by a 5% transitory shock (maroon line) and by 5% permanent shock (navy line). When the country is hit by a negative transitory shock, the output goes down today but it goes up in future as it starts recovering from tomorrow. Thus, with convex cost of default, defaulting tomorrow entails a higher output cost than defaulting today. Since both the lenders and the borrower know this, the lenders endogenize it and the price of debt today goes down. This causes the borrowing or the debt level to go down as well. Thus, for a given value of average debt, the debt distribution is very spread out in the case of transitory shocks. After a negative permanent shock, on the other hand, the output goes down today and it goes down even more in future as it is a growth shock. With convex cost of default, defaulting tomorrow entails a lower output cost than defaulting today. Again, since both the lenders and the borrower know this, the lenders endogenize it and the price of debt today is relatively higher (even if it goes down). This causes the borrowing or the debt to go down but not by a lot. Thus, for a given value of average debt, the debt distribution is very concentrated near the mean in the case of permanent shocks.

A spread out distribution of debt causes countries to accumulate a lot of debt after transitory shocks compared to similar levels of permanent shocks. Additionally, when facing a negative shock after a series of positive shocks, deleveraging required, to stay in non-default status, is much more for the case of transitory shocks compared to the case of permanent shocks. Thus, countries prefer to default rather than undergo painful and huge deleveraging after negative transitory shocks.

Figure 14: Output Drop: Transitory vs Permanent Shock



Note: (1) A shock of -5% hits at t=1 (2) Persistence levels used: ρ_z=0.95 and ρ_g=0.5

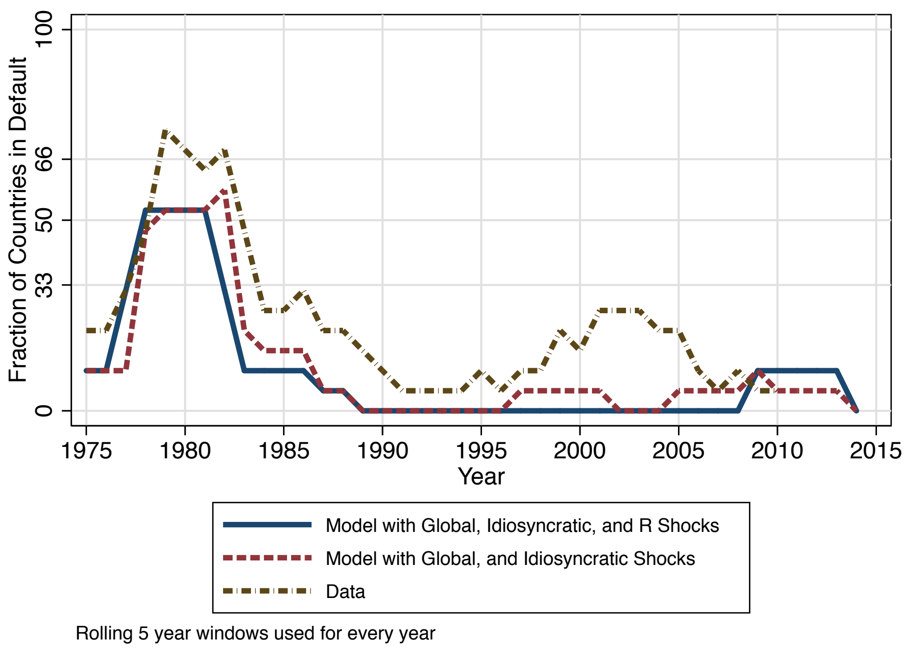
The difference between global and country-specific transitory shocks arises due to high persistence of global transitory shocks. With shocks that have low persistence, the debt level accumulated after a series of positive shocks is not as big as with more persistent shocks. Additionally, after a series of negative shocks that have low persistence, i.e. they last fewer periods, the country does not get as low debt as with more persistent shocks. Combining both side of the arguments, thus the debt distribution is less spread out with less persistent shocks. This is why the dotted navy line is steeper than solid navy line in Figure 13.

The results are different than the ones in Aguiar and Gopinath (2006) because they had proportional default cost. The debt distribution here is much more spread out compared to the case of proportional default cost. In the proportional default cost case, agents do not hold too much debt even after positive transitory shocks. This is because when default cost are proportional, i.e. not convex, the probability of default is higher even at a high level of output. This causes defaults to happen both in good as well as bad times, not specifically in bad times, which is different with convex default costs.

6.3.2 Baseline Model with Stochastic World Interest Rate

This section investigates the contribution of interest rate shocks, through the *debt-pricing channel*, in causing clustered defaults by running two exercises and comparing their results. First, simulating the optimal default choices of countries by using all five shocks – four output shocks and one interest rate shock. Second, by shutting down the interest rate shock and using constant interest rate of 3.67% across all periods from 1960 to 2014. The comparison is shown in Figure 15 and, surprisingly, it shows that the presence of stochastic interest rate *does not* contribute much in causing clustered defaults. Output shocks still explain all the defaults in the clustered default period of 1982. This result goes against the commonly-held belief that Volcker interest rate hike[33] in 1980s was mainly responsible for the emerging country debt crisis of 1982.

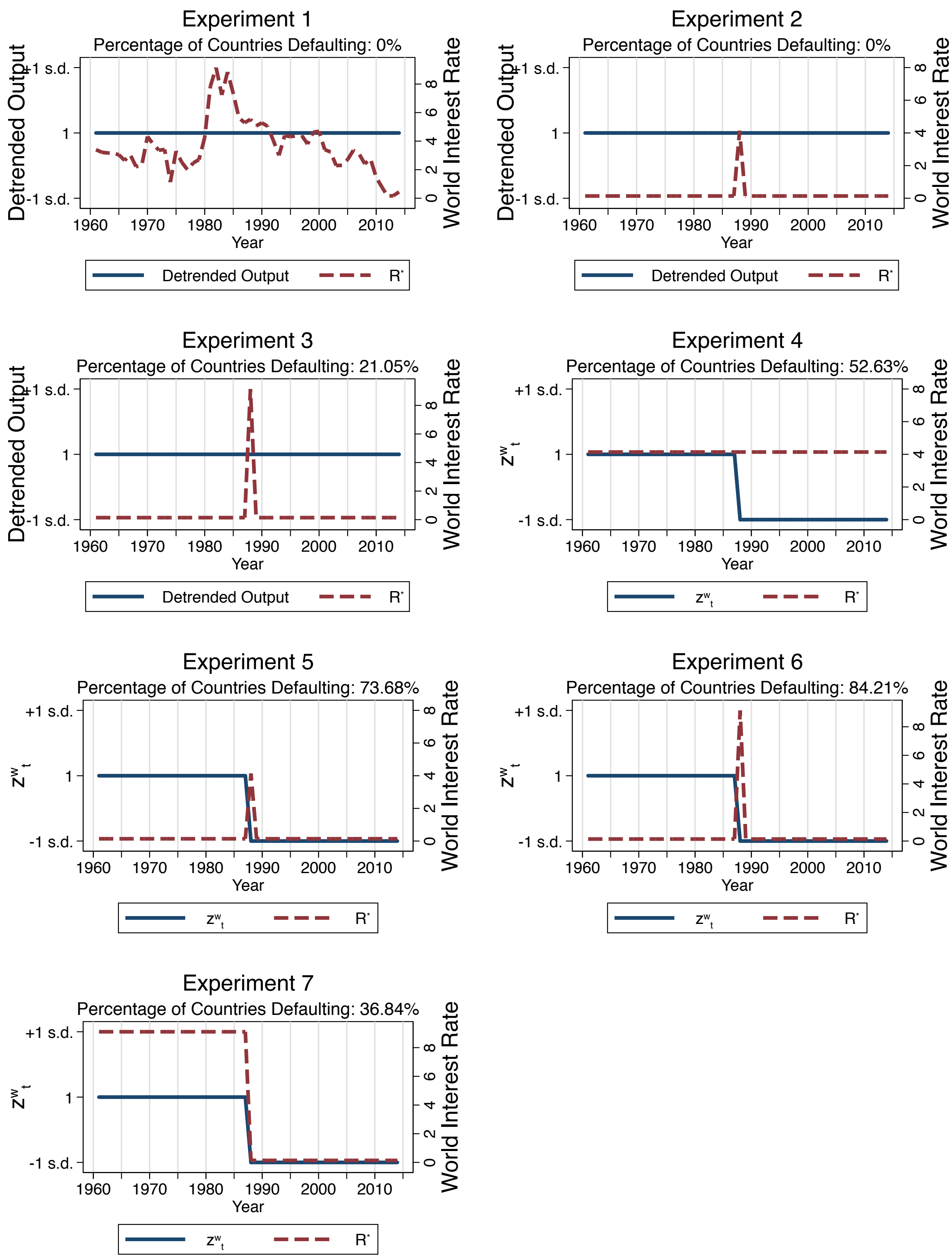
Figure 15: Aggregated default decisions of all countries: Model with world interest rate shocks vs Model without world interest rate shocks vs Data



The result showing a negligible role of Volcker interest rate hike does not rule out the role of interest rate shocks, in general, in causing clustered defaults. To show this, I run a series of experiments and the results of those experiments are shown in Figure 16.

[33] Volcker interest rate hike, in nominal terms, was huge. Even after adjusting for inflation i.e. in real terms, interest rates jumped a lot. This can partly be observed at the start of 1980s from Figure A8 in the appendix.

Figure 16: Percentage of countries defaulting when faced with different output and interest rate shocks



Note: Every country receives the same detrended output series and world interest rate series

For the first three experiments, I simulate the time series of all the countries using detrended output as unity for all the periods from 1961 to 2014. Interest rate shock takes different forms. For the first experiment, the time series of interest rate is exactly the same as observed in the data. Experiment 1 in Figure 16, therefore, shows that without fluctuations in output, the Volcker interest rate hike couldn't have forced any country to default. Thus, output shocks are important in causing defaults.

The absence of defaults when there are no output shocks raises a concern about the effectiveness of interest rate shocks in the model. More specifically, should defaults arise when interest rates go up? This is what I test next: I test if the interest rate shocks can influence default decisions at all in the absence of negative output shocks. Thus, in Experiment 2, I increase the interest rate to 4% for one period in 1988 and it goes back to close to 0 from next period onward.[34] In Experiment 3, I increase the interest rate to 9% for one period in 1988 and it goes back to close to 0 from next period onward. I find that the 4% increase in interest rate is still not enough to cause default even in a single country in the absence of output shocks. An interest rate shock of 9% for one period causes 4 out of 19 countries to default at the onset of interest hike. These countries are: Bolivia, Costa Rica, Guyana and Honduras. Remaining 15 countries prefer to deleverage. The common feature of the countries that default is that they hold high levels of debt. This debt is the debt that is forgotten i.e. not paid back by the borrowers after netting for haircuts.[35] Thus, countries have higher incentives to default if the level of forgotten debt is high. For example, compare two countries with debt level of 10% and 30% of GDP. An increase in risk free rate by 8% causes price of debt to decrease by 8% plus the change in probability of default. If the probability of default doesn't change by a lot, this translates into a change in consumption of 0.8% and 2.4% for the two countries respectively. Thus, if interest rate increase is high enough, countries with high debt have an incentive to default and they can default even in the absence of output shocks.

Having shows that interest rate shocks *can* cause defaults even in the absence of output shocks, the next question I ask is: what happens when the increase in interest rate is accompanied with a decrease in output?

To evaluate the effect of interest rate hike when output decreases, I use changes only in global transitory component of output. Thus, for next four experiments, the global transitory component goes down by 1 standard deviation in 1988 and remains there forever. Given

[34] This increase is similar in magnitude to the Volcker shock but here the interest rate goes up from almost 0. Thus, there is a possibility that the countries might have issued more debt at near 0 rates which can also effect default decision.

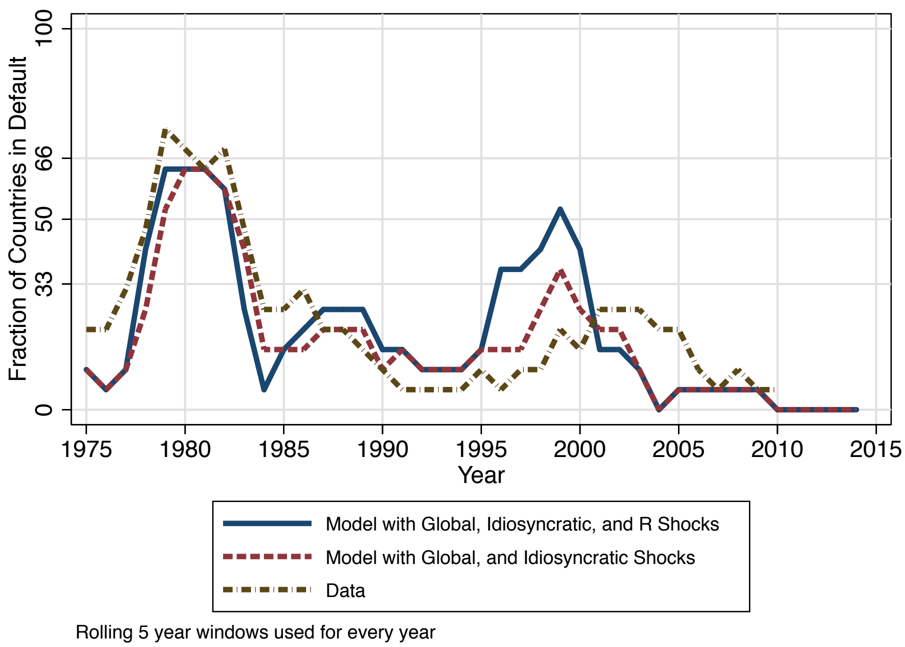
[35] Haircuts are realized investor losses out of the lending. For example, a 90% haircut means 90% of the debt is forgotten.

the change in global transitory component of output, I perform different experiments with interest rate changes. Even when interest remains constant, 10 out of 19 countries default. Thus, output shocks have a much bigger impact compared to interest rate shocks. If the interest rate goes up by 4% for one period but this period coincides with the period of decrease in output, 4 more countries default. If the interest rate goes up by 9% for one period and this period coincides with the period of decrease in output, 6 more countries default taking the total number of defaulters to 16 out of 19. Instead of increasing interest rate, if I decrease the interest rate by 9%, 3 fewer countries default taking the total number of defaulters to 7 out of 19.

The set of experiments show that interest rate shocks can be an important driving force that can cause clustered defaults. Both increase and decrease in interest rate can be a vital policy measure depending on the kind and size of output shocks as well as the debt level in countries. Nonetheless, for the clustered default of 1982, interest rate shocks did not matter much. This is because the output shocks during the 1980s were so big that even if there was no interest rate hike, the countries would have still defaulted. This shows that interest rate policy can be redundant in cases when the countries are feeling huge output shocks.

6.3.3 Extended Model with Stochastic World Interest Rate

Figure 17: Aggregated default decisions of all countries: Extended model with world interest rate shocks vs Extended model without world interest rate shocks vs Data



In the previous part, the effect of interest rate was coming only from the *debt-pricing channel* and not the *endogenous output channel*. Thus, to capture the full effect of interest rate shocks, I go to the full version of the model with stochastic interest rate. I again feed in the time-series of output shocks, time-series of world interest rate from 1960 onward and set the initial level of debt in 1960 to 0. I repeat the same exercise with constant interest rate and compare the two results.

As evident in Figure 17, interest rate shocks still have negligible effect in causing the cluster of 1982. There seems to be an effect of interest rate in the defaults of 1999-2000 though. This again shows that interest rate changes can have an effect on default decision but not when the decline in output is too large, as was the case in early 1980s.

7 Conclusion

In spite of clustered defaults being frequent and costly, a multi-country theoretical framework equipped to study clustered defaults is still lacking. Therefore, this paper studies clustered defaults in a multi-country setup. The essence of the framework of this paper is in: (1) capturing the global shocks – global output shocks and world interest rate shocks – that different countries face, and (2) understanding the mechanism through which these global shocks influence defaults. The framework provides a perfect setting not only to quantify the importance of different shocks in causing clustered defaults, but also to study the role of Volcker interest rate hike on the clustered default of 1982. Equipped with the framework, the paper uncovers two main findings. The first finding shows that global shock to the transitory component of output is the primary driver of clustered defaults. The second finding shows, contrary to what is commonly believed, the Volcker interest-rate hike was not a decisive factor for the 1982 clustered default.

The first essential element of the framework – capturing global shocks – is crucial in order as it disentangles the effects five shocks: transitory and permanent country-specific shocks to output, transitory and permanent global shocks to output, and world interest rate. Thus, a framework like this can be used not only to figure out which countries are more susceptible to global shocks but also to predict how susceptible the world is to a clustered default. Furthermore, knowing more susceptible countries can make bailout policies more targeted in order to avoid the possibility of having clustered defaults.

The second essential element of the framework deals with the mechanism that drives defaults. A unique feature of the model developed here is that it captures the effect of changes in world interest rates on default decisions of borrowing countries through two channels. I call these channels *debt pricing channel* and *endogenous output channel*. The introduction of the two channels makes the default decisions more sensitive to world interest rate changes compared to the existing literature. Thus, a framework like this can also be used to study the interest rate policies of large economies and their spillover effects on the borrowing economies to assess future default probabilities.

Both the essential elements of the framework – capturing the global shocks, and understanding the mechanism through which global shocks influence defaults – makes this study crucial for future policy work on clustered defaults. The same spirit is expressed succinctly in the words of Paul Krugman from Diaz-Alejandro et al. (1984):

... why does it matter how we got where we are? ... If the problems of debtor countries basically reflected irresponsible behavior, such a bailout would provide encouragement for more such behavior in the future. If, on the other hand, the debt crisis can be viewed basically as an act of God (or his earthly manifestation, Paul Volcker), this is not a concern.

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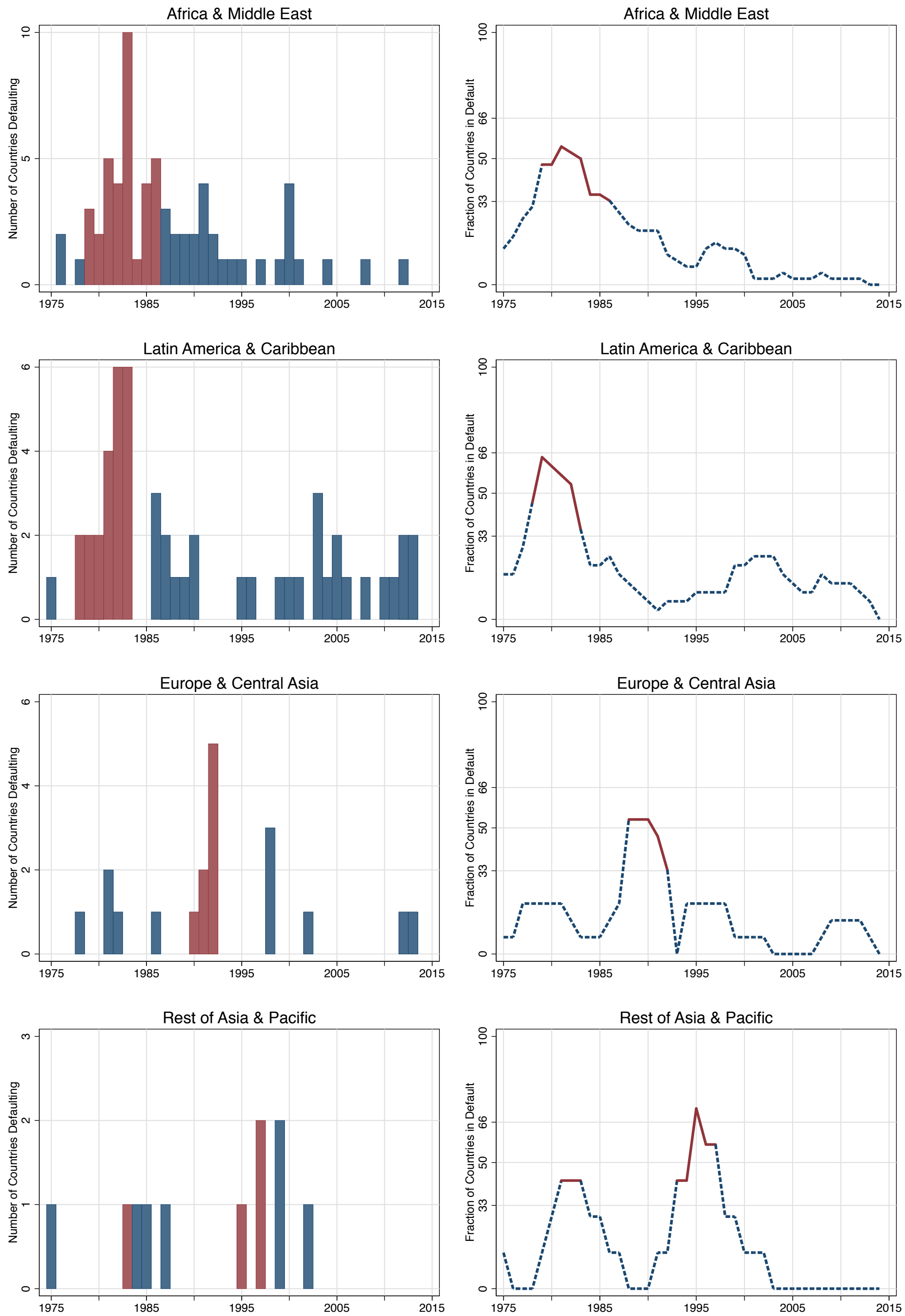
Appendix

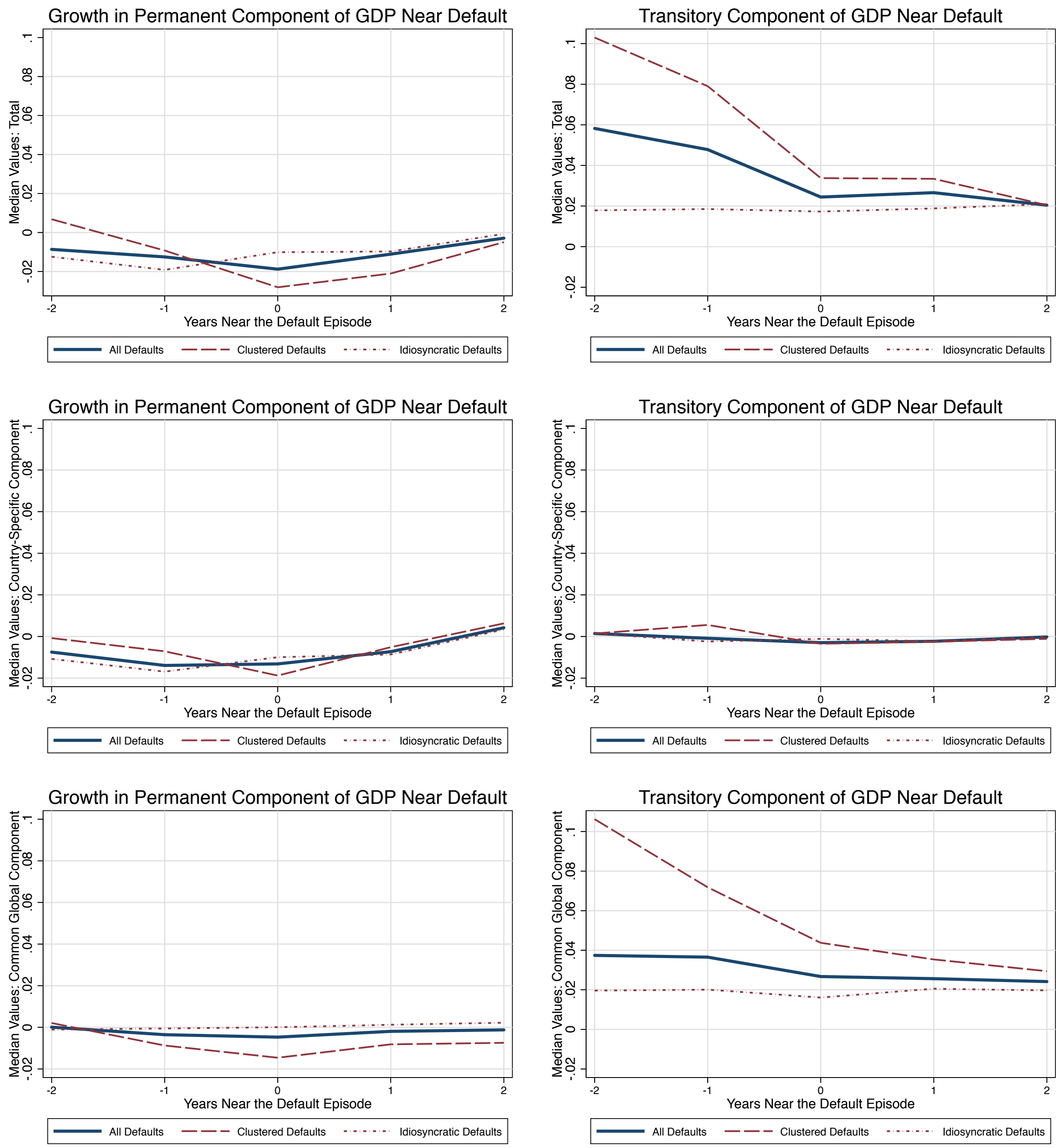
A Figures and Tables

Figure A1: Countries defaulting in a 5-year rolling window by Region



The top panel shows number of countries in default in every year from 1975-2014 at the region level. The bottom panel shows fraction of countries defaulting in a 5-year rolling window starting every year at the region level. Maroon line highlights the period of clustered default while navy line highlights idiosyncratic defaults.

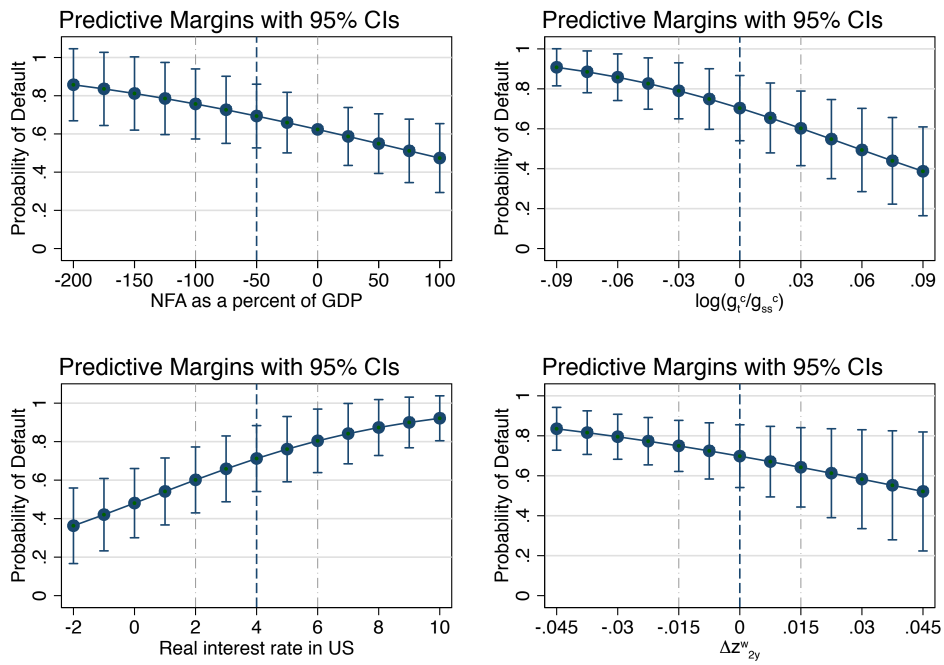
Figure A2: Transitory and Permanent Components of Output Near Default



Note: (1) 0 depicts the crisis year. -1 and -2 depict 1 and 2 years before the crisis while 1 and 2 depict 1 and 2 years after the crisis. (2) The diagram is based on components of output process obtained from estimation using data from 49 defaulting countries and 10 developed countries.

The left panels plot growth rate in the permanent component of GDP. It starts with the total growth rate of permanent component – $\log(g_t^c/g_{ss}^c) + \alpha_X^c \log(g_t^w/g_{ss}^w)$ – in the first row and then decomposes its country-specific and global parts – $\log(g_t^c/g_{ss}^c)$ and $\alpha_X^c \log(g_t^w/g_{ss}^w)$ – respectively. The right panels plot the transitory component of GDP. It starts with the total transitory component – $z_t^c + \alpha_z^c z_t^w$ – in the first row and then decomposes its country-specific and global parts – z_t^c and $\alpha_z^c z_t^w$ – respectively.

Figure A3: Change in Probability with changes in one explanatory



The figure depicts marginal change in probability of default if one explanatory variable changes (keeping all other explanatory variables fixed). The mean value of explanatory variables are highlighted with the vertical dashed line. The dash-dot line represents one standard deviations for respective explanatory variables.

Figure A4: Predicted probabilities: Specifications 1 vs Specifications 2

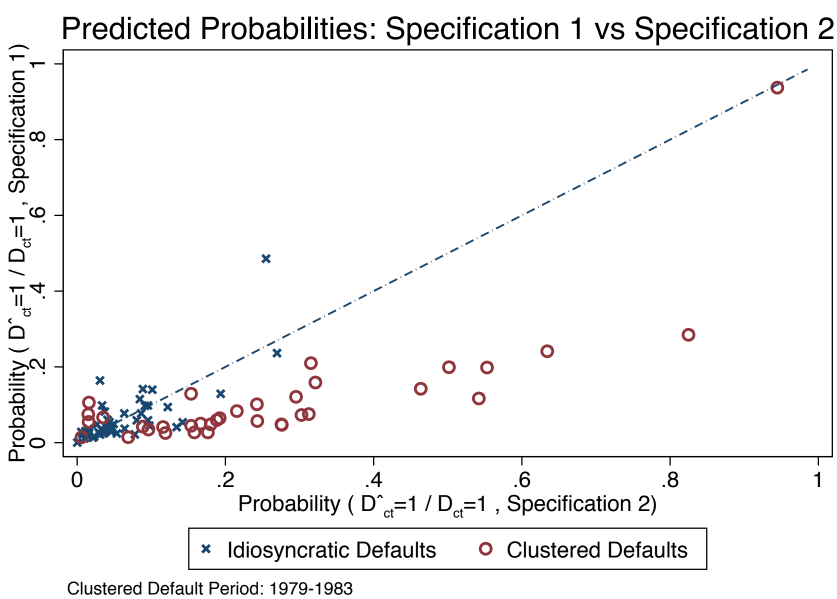
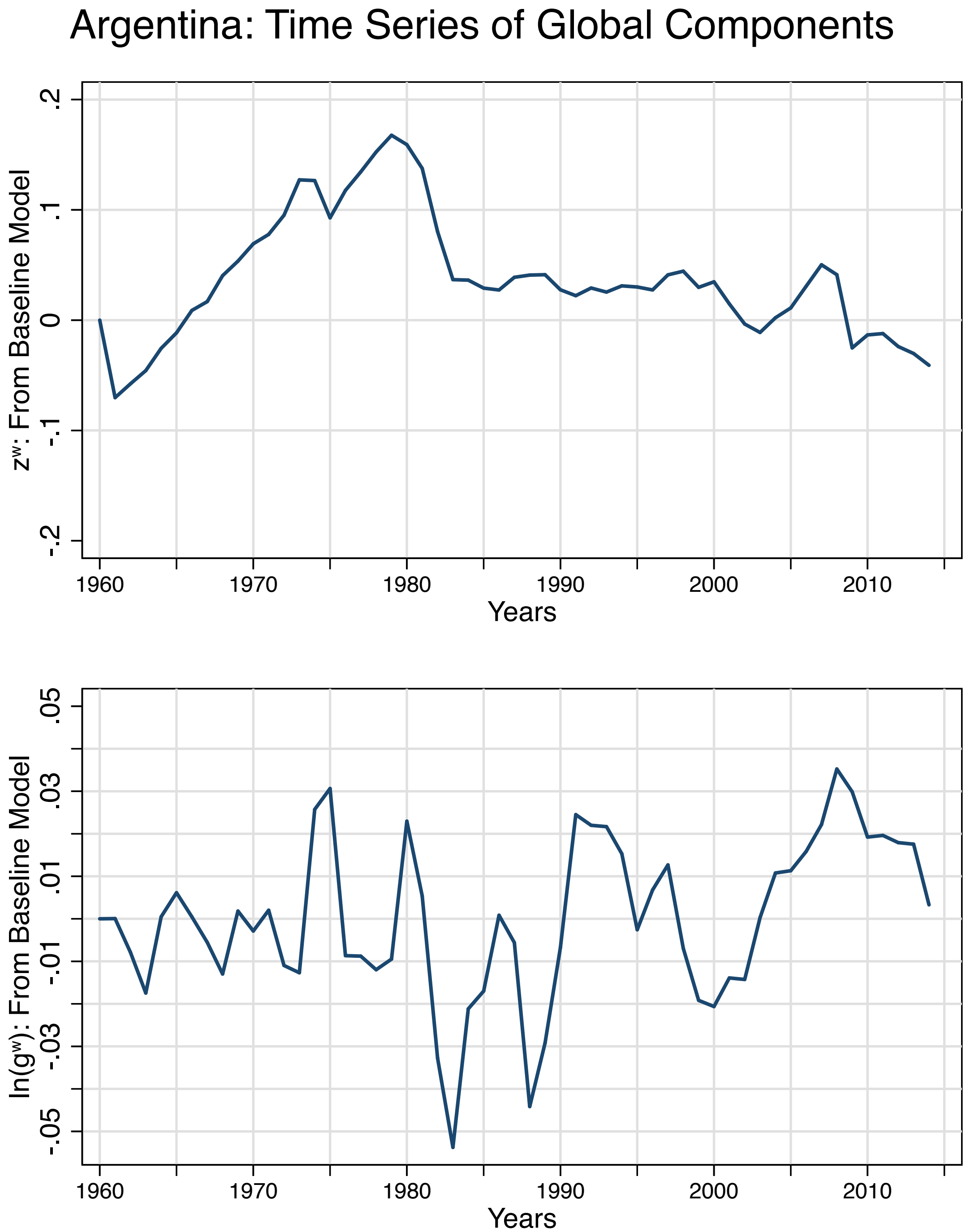
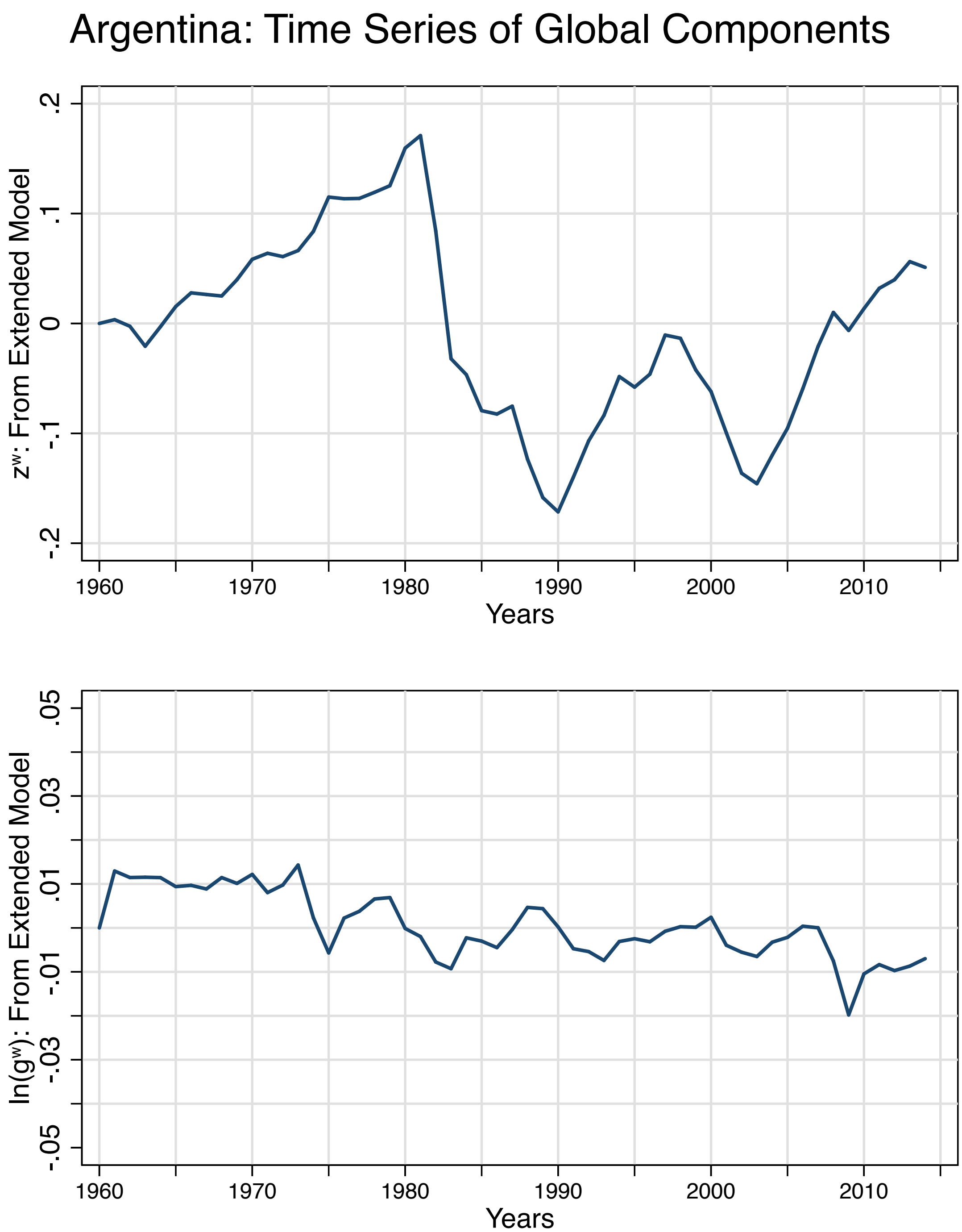


Figure A5: global constituent for the transitory component of output/TFP



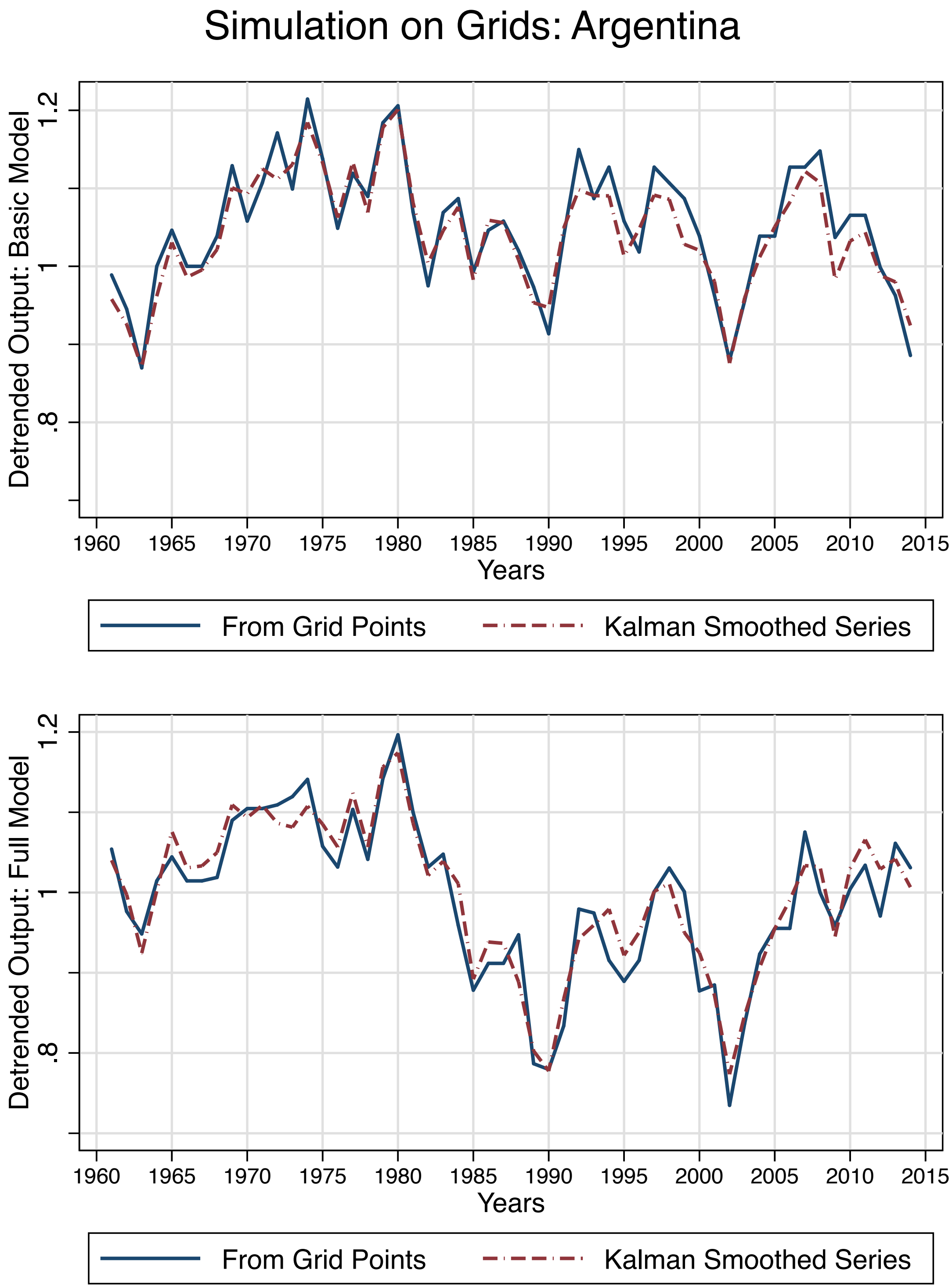
The figure shows global transitory component scaled for Argentina from different models. The top panel shows $\alpha_z^{ARG} z_t^w$ from the basic model. The bottom panel shows $\psi^{ARG} \alpha_z^{ARG} z_t^w$ from the full model.

Figure A6: Global Permanent Component of Output/TFP



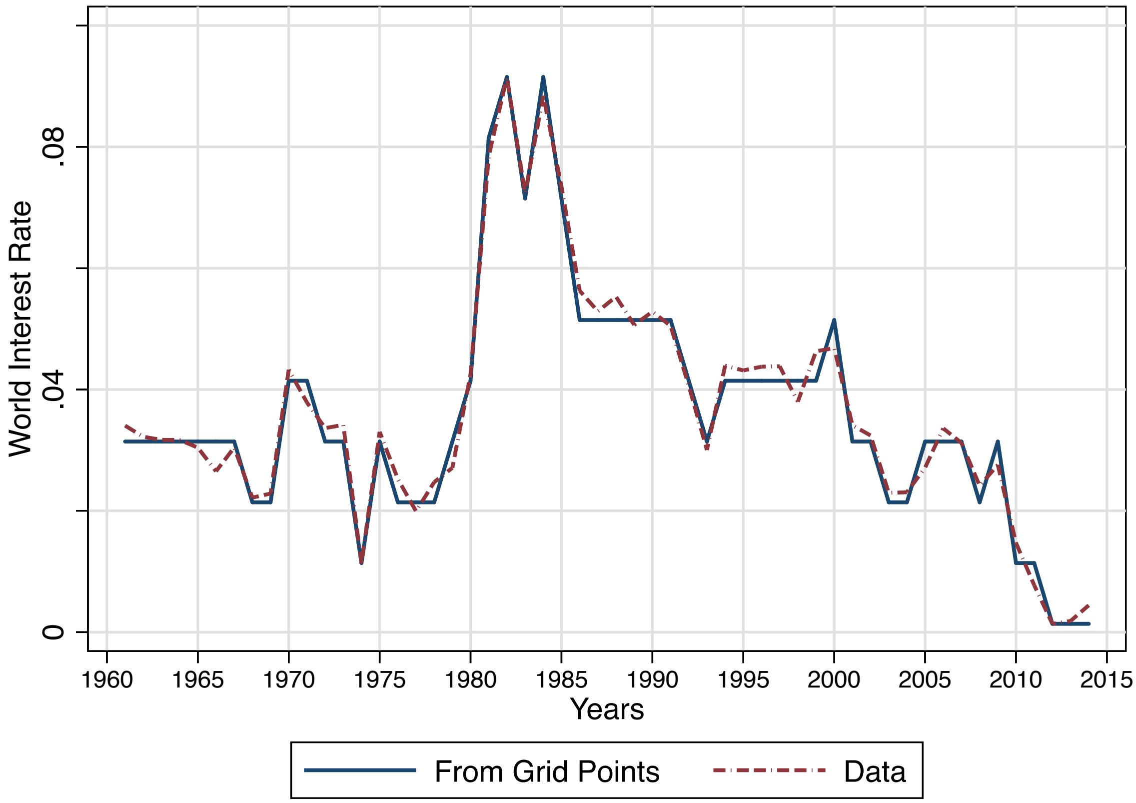
The figure shows growth in global permanent component scaled for Argentina from different models. The top panel shows $\alpha_X^{ARG}\ln(g_t^w)$ from the basic model. The bottom left panel shows $\psi^{ARG}\alpha_X^{ARG}\ln(g_t^w)$ from the full model.

Figure A7: Simulation of Latent state-variables on the Grid



The top panel shows the de-trended output simulated using the grid points and the de-trended output calculated from the series of four Kalman smoothed components of output. The middle panel shows the same two series of de-trended output for the full model.

Figure A8: Simulation of interest rate on grid vs the data



The figure shows the movement of interest rate on a grid of 10 points used in the model and for simulation. It also shows the movement of interest rate in the data.

Table A1: Summary Stats: Explanatory Variables

	Mean	Std. Dev.
Country-Specific Variables		
(NFA as a % of GDP)$_t^c$	-50.160	51.8705
$\log(g_t^c/g_{ss}^c)$	0.001	0.0310
z_t^c	-0.001	0.0397
$\Delta z_{t,t-2}^c$	0.001	0.0387
Global Variables		
(Real interest rate in US)$_t$	3.898	1.9481
$\log(g_t^w/g_{ss}^w)$	-0.003	0.0056
z_t^w	-0.001	0.0238
$\Delta z_{t,t-2}^w$	-0.000	0.0158
(Inflation Adjusted Oil Prices)$_t$	64.560	27.8581
Observations	1220	

Table A2: Logistic Regression Results

	Specification 1		Specification 2)	
	Coefficient	$\frac{d(Prob)}{dx_i}\sigma_{x_i}$	Coefficient	$\frac{d(Prob)}{dx_i}\sigma_{x_i}$
Country-Specific Variables				
(NFA as a % of GDP)$_t^c$	-0.00768***	-0.0876	-0.00678**	-0.0449
$\log(g_t^c/g_{ss}^c)$	-19.49***	-0.1331	-19.88***	-0.0787
z_t^c	-2.554	-0.0223	-2.911	-0.0147
Global Variables				
(Real interest rate in US)$_t$			0.364***	0.0905
$\log(g_t^w/g_{ss}^w)$			25.20	0.0180
z_t^w			-14.82*	-0.0450
(Inflation Adjusted Oil Prices)$_t$			0.00301	0.0107
Country Fixed Effects	Yes		Yes	
N	1220		1220	
pseudo R^2	0.101		0.215	

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A3: Predicted Probability of Default for Default Episodes

		Average(Predicted probability of default conditional on default)		t-stat
Default Type	N0.	Specification 1	Specification 2	$\hat{P}(D=1\|S_1) = \hat{P}(D=1\|S_2)$
Idiosyncratic Default	52	.0634	0.0604	0.4418
Clustered Default	35	0.1148	0.2631	-6.1837

Table A4: Predicted Probability of Default for Non-Default Episodes

		Average(Predicted probability of default conditional on no default)		t-stat
Period	N0.	Specification 1	Specification 2	$\hat{P}(D=1\|S_1) = \hat{P}(D=1\|S_2)$
Non Clustered Default Period	968	0.0360	0.0274	8.0879
Clustered Default Period	165	0.0353	0.0555	-4.0970

Table A5: Prior Distribution for Bayesian Estimation

	Uniform Prior Distributions	
Parameter	Min	Max
ρ_z^c	0.0001	0.99
ρ_g^c	0.0001	0.99
σ_z^c	0.0001	0.9
σ_g^c	0.0001	0.9
ρ_z^w	0.0001	0.99
ρ_g^w	0.0001	0.99
α_z^{VEN}	0.0001	2
α_X^{VEN}	0.0001	2
α_z^c	-2	2
α_X^c	-2	2

σ_z^w and σ_g^w are normalized to 1

Table A6: Prior Distribution for Bayesian Estimation: Full Model

	Uniform Prior Distributions	
Parameter	Min	Max
ρ_z^c	0.0001	0.99
ρ_g^c	0.0001	0.99
σ_z^c	0.0001	0.9
σ_g^c	0.0001	0.9
ρ_z^w	0.0001	0.99
ρ_g^w	0.0001	0.99
ψ^c	1.01	4
η^c	0.0001	0.9999
α_z^{VEN}	0.0001	2
α_X^{VEN}	0.0001	2
α_z^c	-2	2
α_X^c	-2	2

σ_z^w and σ_g^w are normalized to 1

Table A7: Bayesian Estimation Results from Basic Model: Posterior means

Country	Statistic	Posterior (Mean & Standard Deviation)					
		ρ_z^c	ρ_g^c	σ_z^c	σ_g^c	α_z^c	α_X^c
Argentina	Mean	0.5751	0.2774	0.0370	0.0190	0.0190	0.0157
	Std. Dev.	0.2075	0.2019	0.0117	0.0151	0.0207	0.0234
Belize	Mean	0.4532	0.5530	0.0094	0.0301	0.0058	0.0043
	Std. Dev.	0.2310	0.1441	0.0058	0.0047	0.0100	0.0104
Bolivia	Mean	0.6336	0.3433	0.0176	0.0238	0.0052	0.0080
	Std. Dev.	0.2917	0.2002	0.0091	0.0091	0.0110	0.0106
Brazil	Mean	0.2672	0.5619	0.0093	0.0248	0.0165	0.0045
	Std. Dev.	0.1914	0.1560	0.0049	0.0050	0.0123	0.0188
Chile	Mean	0.6647	0.5342	0.0185	0.0305	0.0234	0.0048
	Std. Dev.	0.2495	0.1635	0.0092	0.0083	0.0164	0.0229
Costa Rica	Mean	0.7120	0.2835	0.0158	0.0128	0.0190	0.0015
	Std. Dev.	0.1802	0.1802	0.0060	0.0072	0.0127	0.0162
Dominican Republic	Mean	0.7517	0.3894	0.0397	0.0190	0.0146	0.0025
	Std. Dev.	0.1498	0.2268	0.0117	0.0152	0.0129	0.0154
Ecuador	Mean	0.6620	0.4509	0.0125	0.0210	0.0064	0.0051
	Std. Dev.	0.2388	0.1922	0.0067	0.0063	0.0082	0.0091
Guatemala	Mean	0.4669	0.6373	0.0069	0.0112	0.0121	0.0001
	Std. Dev.	0.3095	0.1878	0.0030	0.0031	0.0088	0.0117
Guyana	Mean	0.6988	0.3202	0.0228	0.0277	0.0092	0.0229
	Std. Dev.	0.2267	0.1896	0.0111	0.0115	0.0258	0.0209
Honduras	Mean	0.5827	0.3248	0.0130	0.0142	0.0174	-0.0010
	Std. Dev.	0.2886	0.1823	0.0067	0.0067	0.0129	0.0141
Mexico	Mean	0.3328	0.3815	0.0094	0.0251	0.0176	0.0041
	Std. Dev.	0.2627	0.1451	0.0058	0.0049	0.0121	0.0183
Nicaragua	Mean	0.6416	0.4959	0.0268	0.0485	0.0026	0.0106
	Std. Dev.	0.2062	0.2308	0.0161	0.0145	0.0191	0.0175
Panama	Mean	0.7705	0.4015	0.0118	0.0313	0.0085	0.0152
	Std. Dev.	0.1549	0.1549	0.0082	0.0067	0.0182	0.0177
Paraguay	Mean	0.5821	0.7096	0.0184	0.0194	0.0173	0.0070
	Std. Dev.	0.2761	0.1758	0.0059	0.0068	0.0125	0.0194
Peru	Mean	0.8125	0.4263	0.0126	0.0329	0.0129	0.0214
	Std. Dev.	0.1149	0.1530	0.0089	0.0068	0.0245	0.0235
Trinidad and Tobago	Mean	0.6563	0.6455	0.0140	0.0322	0.0113	0.0024
	Std. Dev.	0.2137	0.1413	0.0075	0.0070	0.0117	0.0157
Uruguay	Mean	0.5996	0.4348	0.0096	0.0255	0.0151	0.0186
	Std. Dev.	0.2519	0.1715	0.0068	0.0062	0.0201	0.0207
Venezuela, RB	Mean	0.6204	0.3278	0.0333	0.0211	0.0227	0.0074
	Std. Dev.	0.2247	0.2298	0.0121	0.0148	0.0123	0.0213

World	Statistic	ρ_z^w	ρ_g^w
	Mean	0.9414	0.5038
	Std. Dev.	0.0433	0.1599

The countries included in the estimation process are 24. 19 defaulting countries from Latin America & Caribbean and 5 non-defaulting developed countries. Parameter estimates are reported only for 19 Latin America & Caribbean countries.

Table A8: Bayesian Estimation Results from Full Model: Posterior means

Country	Statistic	Posterior (Mean & Standard Deviation)							
		ρ_z^c	ρ_g^c	σ_z^c	σ_g^c	ψ^c	η^c	α_z^c	α_X^c
Argentina	Mean	0.2813	0.6431	0.0134	0.0141	2.0832	0.3924	0.0196	0.0029
	Std. Dev.	0.2314	0.0743	0.0064	0.0076	0.0769	0.0895	0.0055	0.0057
Belize	Mean	0.4934	0.7748	0.0028	0.0138	2.5386	0.3669	0.0041	0.0017
	Std. Dev.	0.0906	0.0757	0.002	0.0017	0.1036	0.148	0.0033	0.0033
Bolivia	Mean	0.9477	0.2448	0.0136	0.0036	2.3502	0.0713	0.0086	-0.0003
	Std. Dev.	0.041	0.1542	0.002	0.0026	0.1037	0.0506	0.0033	0.0032
Brazil	Mean	0.2023	0.8617	0.0025	0.0122	2.2738	0.6329	0.0078	0.0065
	Std. Dev.	0.1091	0.0538	0.0017	0.0016	0.1897	0.1084	0.0034	0.0033
Chile	Mean	0.9267	0.6321	0.011	0.021	1.7075	0.1645	0.0126	0.0082
	Std. Dev.	0.0446	0.1088	0.0067	0.0054	0.0786	0.0873	0.0065	0.0062
Costa Rica	Mean	0.2902	0.5339	0.0039	0.0069	2.3393	0.9032	0.0073	0.0092
	Std. Dev.	0.1159	0.1386	0.0023	0.0024	0.1737	0.0572	0.0028	0.0026
Dominican Republic	Mean	0.3735	0.543	0.0135	0.0235	1.7342	0.8289	0.0078	0.0089
	Std. Dev.	0.0965	0.0731	0.0069	0.0058	0.1156	0.0916	0.0068	0.0054
Ecuador	Mean	0.4392	0.7825	0.0084	0.0142	1.4405	0.7039	0.0092	0.002
	Std. Dev.	0.0925	0.0928	0.004	0.0034	0.1037	0.0857	0.0047	0.0044
Guatemala	Mean	0.7671	0.7034	0.0025	0.0083	1.7201	0.6772	0.0054	0.009
	Std. Dev.	0.0806	0.0687	0.0016	0.0013	0.1368	0.1588	0.0031	0.0029
Guyana	Mean	0.3798	0.6713	0.0037	0.0125	2.9785	0.3414	0.0159	-0.0035
	Std. Dev.	0.1044	0.1285	0.0024	0.002	0.1592	0.0869	0.0037	0.0044
Honduras	Mean	0.4223	0.6674	0.0043	0.0096	2.0775	0.5282	0.005	0.0103
	Std. Dev.	0.1067	0.0843	0.0022	0.0019	0.0552	0.1607	0.0035	0.0033
Mexico	Mean	0.7295	0.7787	0.0057	0.0104	2.0862	0.2603	0.0105	0.0107
	Std. Dev.	0.0982	0.0648	0.0033	0.003	0.0863	0.0706	0.004	0.0041
Nicaragua	Mean	0.9303	0.7011	0.0152	0.0254	2.0281	0.7145	0.0073	-0.0019
	Std. Dev.	0.0465	0.0787	0.0094	0.0082	0.1693	0.1683	0.0078	0.007
Panama	Mean	0.5375	0.8314	0.0039	0.0141	2.5912	0.4966	0.0129	-0.0016
	Std. Dev.	0.1635	0.075	0.0032	0.0026	0.2035	0.1027	0.0043	0.0039
Paraguay	Mean	0.5385	0.6997	0.0047	0.0162	1.8303	0.122	0.0121	0.0081
	Std. Dev.	0.1257	0.1002	0.003	0.0028	0.1154	0.0895	0.0048	0.0046
Peru	Mean	0.4378	0.7591	0.0051	0.0205	1.8	0.268	0.0239	-0.002
	Std. Dev.	0.1151	0.0907	0.0037	0.0029	0.1233	0.0781	0.0068	0.0062
Trinidad and Tobago	Mean	0.1823	0.8532	0.004	0.0177	1.9957	0.0632	0.0054	0.0079
	Std. Dev.	0.1085	0.049	0.0027	0.0022	0.0816	0.0516	0.0047	0.0045
Uruguay	Mean	0.9247	0.7466	0.0088	0.0117	1.7514	0.7631	0.0261	0.0001
	Std. Dev.	0.0489	0.107	0.0049	0.0051	0.0682	0.1214	0.0054	0.0065
Venezuela, RB	Mean	0.8535	0.5335	0.0174	0.0105	2.0829	0.3363	0.0129	0.008
	Std. Dev.	0.0943	0.1222	0.0062	0.0077	0.1941	0.1569	0.0054	0.0043

World	Statistic	ρ_z^w	ρ_g^w
	Mean	0.8897	0.7555
	Std. Dev.	0.0845	0.0957

The countries included in the estimation process are 24. 19 defaulting countries from Latin America & Caribbean and 5 non-defaulting developed countries. Parameter estimates are reported only for 19 Latin America & Caribbean countries.

B Estimation Equations

B.1 State Space Form: The Basic Version

Measurement Equation

$$\Delta y_t = W + V \cdot \theta_t$$

where,

$$\Delta y_t = \left[\Delta y_t^1, \cdot, \Delta y_t^c, \cdot, \Delta y_t^{nc}\right]^{\mathrm{T}}$$

$$W = \left[\ln(g_{ss}^1) + \alpha_X^1 \ln(g_{ss}^w), \cdot, \ln(g_{ss}^c) + \alpha_X^c \ln(g_{ss}^w), \cdot, \ln(g_{ss}^{nc}) + \alpha_X^{nc} \ln(g_{ss}^w)\right]^{\mathrm{T}}$$

$$V = \begin{bmatrix} \alpha_z^1 & -\alpha_z^1 & \alpha_X^1 & 1 & -1 & 1 & \cdot & 0 & 0 & 0 & \cdot & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \alpha_z^c & -\alpha_z^c & \alpha_X^c & 0 & 0 & 0 & \cdot & 1 & -1 & 1 & \cdot & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \alpha_z^{nc} & -\alpha_z^{nc} & \alpha_X^{nc} & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & \cdot & 1 & -1 & 1 \end{bmatrix}$$

and

$$\theta_t = \Big[\; z_t^w \quad z_{t-1}^w \quad \ln(g_t^w/g_{ss}^w) \quad z_t^1 \quad z_{t-1}^1 \quad \ln(g_t^1/g_{ss}^1) \quad \cdot \quad z_t^c \quad z_{t-1}^c \quad \ln(g_t^c/g_{ss}^c) \quad \cdot$$
$$\cdot \quad z_t^{nc} \quad z_{t-1}^{nc} \quad \ln(g_t^{nc}/g_{ss}^{nc}) \;\Big]^{\mathrm{T}}$$

The dimension of Δy_t is $(nc \times 1)$. W is also $(nc \times 1)$ and it is time invariant. V is $(nc \times (3 * nc + 3))$ and it is time invariant as well. The state variable vector, θ_t, is $((3 * nc + 3) \times 1)$.

Transition Equation

The evolution of state vector (transition equation) can be represented as:

$$\theta_t = K \cdot \theta_{t-1} + \lambda_t$$

where $\lambda_t = \left[\epsilon_{z,t}^w, 0, \epsilon_{g,t}^w, \epsilon_{z,t}^1, 0, \epsilon_{g,t}^1, \cdot, \epsilon_{z,t}^c, 0, \epsilon_{g,t}^c, \cdot, \epsilon_{z,t}^{nc}, 0, \epsilon_{g,t}^{nc}\right]^{\mathrm{T}}$, $\epsilon_z^w \sim N(0, (\sigma_z^w)^2)$, $\epsilon_g^w \sim N(0, (\sigma_g^w)^2)$, $\epsilon_z^c \sim N(0, (\sigma_z^c)^2)$, $\epsilon_g^c \sim N(0, (\sigma_g^c)^2)$ and

$$K = \begin{bmatrix} \rho_z^w & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & \cdot & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & \cdot & 0 & 0 & 0 \\ 0 & 0 & \rho_g^w & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & \cdot & 0 & 0 & 0 \\ 0 & 0 & 0 & \rho_z^1 & 0 & 0 & \cdot & 0 & 0 & 0 & \cdot & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & \cdot & 0 & 0 & 0 & \cdot & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \rho_g^1 & \cdot & 0 & 0 & 0 & \cdot & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdot & \rho_z^c & 0 & 0 & \cdot & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdot & 1 & 0 & 0 & \cdot & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & \rho_g^c & \cdot & 0 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & \cdot & \rho_z^{nc} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & \cdot & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & \cdot & 0 & 0 & \rho_g^{nc} \end{bmatrix}$$

B.2 State SpaceForm: The Full Version

Measurement Equation

$$\Delta y_t = W_t + V \cdot \theta_t$$

where,

$$\Delta y_t = \left[\Delta y_t^1, \cdot, \Delta y_t^c, \cdot, \Delta y_t^{nc}\right]^{\mathrm{T}}$$

$$\begin{aligned} W_t = \big[&\ln(g_{ss}^1) + \alpha_X^1 \ln(g_{ss}^w) - (\psi^1 - 1)\eta^1 \Delta r_t^*, \cdot, \ln(g_{ss}^c) + \alpha_X^c \ln(g_{ss}^w) - (\psi^c - 1)\eta^c \Delta r_t^*, \cdot \\ &, \ln(g_{ss}^{nc}) + \alpha_X^{nc} \ln(g_{ss}^w) - (\psi^{nc} - 1)\eta^{nc} \Delta r_t^*\big]^{\mathrm{T}} \end{aligned}$$

$$\begin{aligned} \theta_t = \big[&z_t^w, z_{t-1}^w, \ln(g_t^w/g_{ss}^w), \ln(g_{t-1}^w/g_{ss}^w), z_t^1, z_{t-1}^1, \ln(g_t^1/g_{ss}^1), \ln(g_{t-1}^1/g_{ss}^1), \cdot, z_t^c, z_{t-1}^c, \\ &\ln(g_t^c/g_{ss}^c), \ln(g_{t-1}^c/g_{ss}^c), \cdot, z_t^{nc}, z_{t-1}^{nc}, \ln(g_t^{nc}/g_{ss}^{nc}), \ln(g_{t-1}^{nc}/g_{ss}^{nc})\big]^{\mathrm{T}} \end{aligned}$$

and

$$V = \begin{bmatrix} \psi^1\alpha_z^1 & \cdot & \psi^c\alpha_z^c & \cdot & \psi^{nc}\alpha_z^{nc} \\ -\psi^1\alpha_z^1 & \cdot & -\psi^c\alpha_z^c & \cdot & -\psi^{nc}\alpha_z^{nc} \\ \psi^1\alpha_X^1 & \cdot & \psi^c\alpha_X^c & \cdot & \psi^{nc}\alpha_X^{nc} \\ -(\psi^1-1)\alpha_X^1 & \cdot & -(\psi^c-1)\alpha_X^c & \cdot & -(\psi^{nc}-1)\alpha_X^{nc} \\ \psi^1 & \cdot & 0 & \cdot & 0 \\ -\psi^1 & \cdot & 0 & \cdot & 0 \\ \psi^1 & \cdot & 0 & \cdot & 0 \\ -(\psi^1-1) & \cdot & 0 & \cdot & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & \cdot & \psi^c & \cdot & 0 \\ 0 & \cdot & -\psi^c & \cdot & 0 \\ 0 & \cdot & \psi^c & \cdot & 0 \\ 0 & \cdot & -(\psi^c-1) & \cdot & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & \cdot & 0 & \cdot & \psi^{nc} \\ 0 & \cdot & 0 & \cdot & -\psi^{nc} \\ 0 & \cdot & 0 & \cdot & \psi^{nc} \\ 0 & \cdot & 0 & \cdot & -(\psi^{nc}-1) \end{bmatrix}^T$$

The dimension of Δy_t is $(nc \times 1)$ (where nc is the total number of countries). W_t is not time invariant now as it depends on changes in world interest rate. The dimension of W_t is also $(nc \times 1)$. V is $(nc \times (4 * nc + 4))$ and it is still time invariant as before. The state variable θ_t is $((4 * nc + 4) \times 1)$.

Transition Equation

The evolution of state vector (transition equation) is represented as:

$$\theta_t = K \cdot \theta_{t-1} + \lambda_t$$

where

$$K = \begin{bmatrix}
\rho_z^w & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 \\
0 & 0 & \rho_g^w & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \rho_z^w & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \rho_g^w & 0 & \cdot & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & \cdot & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdot & \rho_z^w & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdot & 1 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & \rho_g^w & 0 & \cdot & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 1 & 0 & \cdot & 0 & 0 & 0 & 0 \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 & \cdot & \rho_z^w & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 & \cdot & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & \rho_g^w & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 0 & 0 & \cdot & 0 & 0 & 1 & 0\cdot
\end{bmatrix}$$

and $\lambda_t = [\epsilon^w_{z,t}, 0, \epsilon^w_{g,t}, 0, \epsilon^1_{z,t}, 0, \epsilon^1_{g,t}, 0, \cdot, \epsilon^c_{z,t}, 0, \epsilon^c_{g,t}, 0, \cdot, \epsilon^{nc}_{z,t}, 0, \epsilon^{nc}_{g,t}, 0]^{\mathrm{T}}$, $\epsilon^w_z \sim N(0, (\sigma^w_z)^2)$, $\epsilon^w_g \sim N(0, (\sigma^w_g)^2)$, $\epsilon^c_z \sim N(0, (\sigma^c_z)^2)$ and $\epsilon^c_g \sim N(0, (\sigma^c_g)^2)$.

C Model Equations

C.1 Baseline Version of the Model: Equations

Households

In the baseline version, the household gets utility only from consumption of the final good

$$U(C_t, L_t^s) = \left[\frac{C_t^{1-\gamma}}{1-\gamma}\right]$$

where γ represents the Arrow-Pratt measure of relative risk aversion

Every period households gets exogenous endowment in the form of output and transfer from the government. The household budget constraint is therefore given as:

$$C_t = Y_t + T_t \tag{12}$$

Since both output and transfers are given, households consumption level is also given and there is no optimization problem to solve for the household. The government decides the level of transfer in order to maximize household utility. The equations of the baseline version of the model are kept in a similar as the full model. Alternatively, we can allow household to borrow from rest of the world and make debt, default and consumption decisions. In terms of the model equations and the solution, this alternative way is exactly the same as the current version of the of the baseline model.

Government

The aim of benevolent social planner or the government is to maximize the utility of the households. Therefore, the government's problem remains the same as in the full version of the model.

The amount borrowed, net of repayments, is again the transfer when government decides not to default:

$$T_t = q_t d_{t+1} - d_t \tag{13}$$

When the government decides to default, there is no additional borrowing and government transfer is 0.

The the continuation payoff i.e. value function when the agent doesn't default and continues to repay the debt, is given as:

$$V^C(d_t; z_t, z_t^w, X_t, X_t^w, r_t^*) = \max_{c_t, d_{t+1}} [u(c_t) + \beta E_{y,r}[V^G(d_{t+1}; z_{t+1}, z_{t+1}^w, X_{t+1}, X_{t+1}^w, r_{t+1}^*)] \tag{14}$$

subject to the household budget constraint and the government transfer condition. Here V^G represents the value function when the agent enters the period with good financial standing ($f = 0$).

The continuation payoff in bad standing is given as:

$$\begin{aligned} V^B(z_t, z_t^w, X_t, X_t^w, r_t^*) = u(c_t^A) + \beta E_{y,r}\{\lambda V^G[(0; z_{t+1}, z_{t+1}^w, X_{t+1}, X_{t+1}^w, r_{t+1}^*) \\ + (1-\lambda) V^B(z_{t+1}, z_{t+1}^w, X_{t+1}, X_{t+1}^w, r_{t+1}^*)\} \end{aligned} \tag{15}$$

subject to the household budget constraint and that the transfer to households is now 0. In this case, the function ϕ, that governs output loss in default, will also be non-zero. The function ϕ and thus, the output loss in default depends on individual technology shocks.

The continuation payoff when agent starts a period in good standing:

$$V^G(d_t; z_t, z_t^w, X_t, X_t^w, r_t^*) = \max\{V^C(d_t; z_t, z_t^w, X_t, X_t^w, r_t^*), V^B(z_t, z_t^w, X_t, X_t^w, r_t^*)\} \tag{16}$$

The default rule is therefore be given as:

$$F(d_t; z_t, z_t^w, X_t, X_t^w, r_t^*) = \begin{cases} 1 & \text{if } V^B(z_t, z_t^w, X_t, X_t^w, r_t^*) > V^C(d_t; z_t, z_t^w, X_t, X_t^w, r_t^*) \\ 0 & \text{otherwise} \end{cases} \tag{17}$$

Lender

The last piece of the model is to explain the lender side. I assume a large number of risk neutral lenders. Risk free return is therefore adjusted for the probability of default to get rate of return on debt.

$$(1+r_t)\times Prob_{y,r}(V^C(d_{t+1}; z_{t+1}, z_{t+1}^w, X_{t+1}, X_{t+1}^w, r_{t+1}^*) > V^B(z_{t+1}, z_{t+1}^w, X_{t+1}, X_{t+1}^w, r_{t+1}^*)) = 1+r_t^*$$

Given that the price of debt, $q_t = 1/(1+r_t)$, we have

$$q_t(d_{t+1}; z_t, z_t^w, X_t, X_t^w, r_t^*) = \frac{Prob_{y,r}(V_{t+1}^C > V_{t+1}^B)}{1+r_t^*} \tag{18}$$

C.2 Equations in Detrended Form

All the equations and time t variables are detrended by $\Gamma_{t-1}^c \equiv X_{t-1}^c (X_{t-1}^w)^{\alpha_X^c} \cdot \mu_g^c (\mu_g^w)^{\alpha_X^c}$ and a detrended variable ν after detrending becomes $\tilde{\nu}_t = \frac{\nu_t}{\Gamma_{t-1}}$. Thus the detrended output is given as:

$$\tilde{Y}_t = e^{z_t + \alpha_z z_t^w} g_t (g_t^w)^{\alpha_X} / (\mu_g (\mu_g^w)^{\alpha_X})$$

The budget constraint of the household when not in default is given as:

$$c_t = y_t + q_t d_{t+1} - d_t$$

$$\implies \frac{c_t}{\Gamma_{t-1}} = \frac{y_t}{\Gamma_{t-1}} + \frac{q_t d_{t+1}}{\Gamma_{t-1}} - \frac{d_t}{\Gamma_{t-1}}$$

$$\implies \tilde{c}_t = \tilde{y}_t + \frac{\Gamma_t}{\Gamma_{t-1}} \frac{q_t d_{t+1}}{\Gamma_t} - \tilde{d}_t$$

$$\implies \tilde{c}_t = \tilde{y}_t + g_t (g_t^w)^{\alpha_X} \cdot q_t \tilde{d}_{t+1} - \tilde{d}_t$$

In a similar fashion, we can detrend the utility function and hence the value functions too. The only difference is that we detrend them by $(\Gamma_{t-1})^{1-\gamma}$ instead of Γ_{t-1}. This is because of the peculiar form of utility function used.[36] The detrended utility function can thus be written as:

$$\tilde{u}(\tilde{c_t}) \equiv \frac{u(c_t)}{(\Gamma_{t-1})^{1-\gamma}} = \frac{\tilde{c_t}^{1-\gamma}}{1-\gamma}$$

The value functions can also be detrended in the same way. The continuation value is given as:

$$v^c(y_t, d_t) = \max_{d_{t+1}} \{u(y_t + q_t d_{t+1} - d_t) + \beta \cdot E\left[v^g(y_{t+1}, d_{t+1})\right]\}$$

$$\implies \frac{v^c(y_t, d_t)}{(\Gamma_{t-1})^{1-\gamma}} = \max_{\tilde{d}_{t+1}} \left\{\tilde{u}(\tilde{y_t} + g_t(g_t^w)^{\alpha_X} \cdot q_t\tilde{d}_{t+1} - \tilde{d}_t) + \beta \cdot \frac{(\Gamma_t)^{1-\gamma}}{(\Gamma_{t-1})^{1-\gamma}} \frac{E\left[v^g(y_{t+1}, d_{t+1})\right]}{(\Gamma_t)^{1-\gamma}}\right\}$$

$$\implies \tilde{v^c}(\tilde{y_t}, \tilde{d_t}) = \max_{\tilde{d}_{t+1}} \left\{\tilde{u}(\tilde{y_t} + g_t(g_t^w)^{\alpha_X} \cdot q_t\tilde{d}_{t+1} - \tilde{d}_t) + \beta \cdot (g_t(g_t^w)^{\alpha_X})^{1-\gamma} \cdot E\left[\tilde{v^g}(\tilde{y}_{t+1}, \tilde{d}_{t+1})\right]\right\}$$

The value function when the country defaults or is in bad standing is given by:

$$v^b(y_t) = u\left(y \cdot (1 - \phi(z_t, z_t^w, g_t, g_t^w))\right) + \beta \cdot E\left[\lambda v^g(y_{t+1}, 0) + (1-\lambda) v^b(y_{t+1})\right]$$

$$\implies \tilde{v^b}(\tilde{y_t}) = \tilde{u}\left(\tilde{y_t} \cdot (1 - \phi(z_t, z_t^w, g_t, g_t^w))\right) + \beta \cdot (g_t(g_t^w)^{\alpha_X})^{1-\gamma} \cdot E\left[\lambda \tilde{v^g}(\tilde{y}_{t+1}, 0) + (1-\lambda)\tilde{v^b}(\tilde{y}_{t+1})\right]$$

Detrended version of value function in good standing is:

$$v^g(y_t, d_t) = \max\left\{v^b(y_t), v^c(y_t, d_t)\right\}$$

$$\implies \tilde{v^g}(\tilde{y_t}, \tilde{d_t}) = \max\left\{\tilde{v^b}(\tilde{y_t}), \tilde{v^c}(\tilde{y_t}, \tilde{d_t})\right\}$$

[36] which is why we use $u(c) = \frac{c^{1-\gamma}}{1-\gamma}$ instead of $u(c) = \frac{c^{1-\gamma}-1}{1-\gamma}$