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SOVEREIGN DEFAULT, TRADE, AND TERMS OF TRADE

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Sovereign defaults are associated with income and trade reductions and terms-of-trade deterioration. This paper develops a two-country model to study the interactions between income, trade, terms of trade, and foreign-debt default risk and default events. Such default risk and events are costly because they adversely affect the demand for a borrower country's intermediate goods exports and its income. Consequently, trade flows change due to the income loss and consumption home bias. The defaulter's terms of trade also deteriorate endogenously, which accelerates its income and trade losses. The model produces procyclical imports, exports, terms of trade, and other empirical features of emerging countries' business cycles and default episodes.

Keywords: Sovereign Default, Terms of Trade, Trade Flows, Vertical Export

1. INTRODUCTION

Sovereign debt default events are associated with three empirical regularities: (a) deep recessions, (b) declines in international goods trade, and (c) deteriorating terms of trade and real exchange rates. Recent evidence shows that, across countries, default episodes have on average been accompanied by a GDP drop of 5% below trend, a bilateral trade value decline of 8%, and real depreciation of 30–50%.[1] However, these three phenomena have not been addressed simultaneously by existing sovereign default models. This paper fills the gap by studying how foreign-debt default risk and occurrences endogenously interact with income, terms of trade, and international goods trade in a two-country DSGE model.[2]

The model features four key elements. First, the model has default risk and occurrences as in Eaton and Gersovitz (1981), Aguiar and Gopinath (2006), Arellano (2008), and Mendoza and Yue (2012). The second key element is consumption home bias in both countries. In the model, I show that as the borrower

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country's default risk increases with debt, its budget constraint tightens and its terms of trade deteriorate due to the home bias and reduced world relative demand for its final goods. Deterioration in the terms of trade prevents the borrower country from real appreciation that could have eased the debt burden denominated in the creditor country's final goods. Thus, the default risk increases further. In this way, the default risk interacts with the terms of trade and the real exchange rate *prior* to a sovereign default.

The third key element is borrower country exporting intermediate goods to the creditor country. Historical data from the World Bank show that Latin American (LA) intermediate goods exports were twice as much as their intermediate goods imports during late 1980s and have been at least as important as the intermediate imports since then.[3] Yet, past sovereign default papers that use LA countries as their samples focus on the latter instead of the former. This paper's model fills the literature gap by focusing on the intermediate goods export changes during default episodes. By not including both intermediate exports and intermediate imports in one model, this paper can distinguish the effect of the former from that of the latter. Nevertheless, in the Online Appendix I layout an alternative model setup to compare the baseline model's results with the effect of intermediate goods imports during defaults.

The last key element of the model is a default penalty through the global vertical supply chain: when a large adverse productivity shock causes the borrower country to default, the event triggers an efficiency loss in using the imported intermediate goods input from the defaulting country for the final goods production in the creditor country. This causes the demand for the defaulting country's intermediate goods to decline. Hence, the default-triggered efficiency loss is essentially a negative foreign demand shock to the defaulting country's intermediate goods export. This negative foreign demand shock is consistent with data observations where defaulting countries' *intermediate goods export volume* declines and their terms of trade deteriorate. It is worth noting that the model mechanism is contingent on this default-triggered negative demand shock, but not on hurting the creditor country's production through the efficiency loss. An input taste shock to the creditor country have the same effect.

Empirical exercises indicate such an efficiency loss exists. Specifically, this paper finds that, controlling other factors, US manufacturing output was statistically significantly reduced by 0.7–4.3% below trend by LA default events in the 1980s. More importantly, the size of the impact increases with an industry's dependency on LA inputs. This evidence supports the model setup where the default-triggered efficiency loss affects only the production that uses the imported intermediate goods input from the defaulting country, but not those productions that do not use it in the creditor country. Moreover, this efficiency loss is also consistent with other papers' empirical findings that foreign firms' vertical production with a crisis country (e.g., FDI, offshoring, and other global sourcing) is more severely damaged than the crisis country's domestic firms' production

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(Brennan and Cao (1997), Aizenman and Marion (2004), Tille and van Wincoop (2008), Fuentes and Saravia (2010), Milesi-Ferretti and Tille (2010), and Broner et al. (2013)).

Hence, it is useful to think about the micro-foundation behind such a default-triggered efficiency loss in using the defaulting country's intermediate goods. It can come from several sources. The efficiency loss can be due to crisis-elevated trade costs, such as increasingly expensive trade credits and worker strikes on exporting docks in the defaulting country. It can also be due to risk averse firm managers in the creditor countries becoming more concerned about crisis-elevated political uncertainty and information asymmetry in the defaulting country, which makes it more costly to monitor the situation and continue using the imported intermediate goods from the defaulting country. Therefore, the creditor country's demand for the defaulting country's intermediate goods declines.

This reduction of foreign demand for the intermediate goods upon default in the model generates an income loss additional to that from the initial adverse productivity shock in the defaulting country. Its wealth declines relative to the creditor country's, which reduces the world relative demand of the defaulting country's final goods due to home bias in consumption. Therefore, its terms of trade and real exchange rate deteriorate, taking another toll on income and trade. In this way, the model builds an endogenous terms-of-trade mechanism by which a sovereign default amplifies the effects of the original adverse productivity shocks on the borrower country's income and trade.[4]

This paper contributes to the literature by studying the endogenous consequences of sovereign default risk and default events to income, trade, terms of trade, and real exchange rate, and thus how they affect the incentives to default. In particular, it is the first theoretical sovereign-debt-trade paper to account for both procyclical export and import flows and post-default terms-of-trade deterioration and real depreciation. On the one hand, it is well studied in the empirical literature (e.g., Rose (2005)) that trade flows decrease during default episodes, but little has been done in the theoretical literature to rationalize the phenomenon. Modeling this stylized fact prepares us to begin to think about how a country's consumer preferences regarding home goods and imports affect its propensity to default (Rose and Spiegel (2004) and Rose (2005)).[5]

On the other hand, this paper endogenizes terms of trade and real exchange rate in a sovereign default model. It captures their two-way interaction with default risk not only prior to sovereign default occurrences but also *afterwards*. More specifically, when sovereign defaults occur, the model captures the terms of trade and real exchange rate deterioration as they contribute to the defaulting country's income and trade losses. For instance, for 45 sovereign default episodes in 27 developing countries over the period 1977–2009, on average at least half of the defaulting countries' losses of output and export value came from real depreciation.[6] Therefore, the terms of trade and real exchange rate in my model results in an *endogenous* penalty on income and trade upon default. That is, unlike many

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previous sovereign default models, this model does not rely on an exogenous output loss to the defaulting country.

In a quantitative exercise, I calibrate the model to the LA debt crises in the 1980s. I use the LA countries as a group for the borrower country. In history, we observe that sovereign default events tend not to be isolated one-country events.[7] I use the USA as the creditor country. The time period is 1981Q1–2012Q4. This model generates two results that are unique in sovereign debt literature and are empirical features of emerging markets' business cycles and their sovereign default episodes. First, it delivers procyclical trade flows. Second, the model accounts for terms-of-trade deterioration, real depreciation, and trade flow, and GDP declines during and after a sovereign default.

To further study the mechanism of this paper, I conduct comparative analyses on the efficiency loss as a default penalty, and the degrees of vertical integration and consumption home bias, respectively. In particular, the analyses reveal that lower efficiency loss, lower vertical integration, and higher home bias can decrease a borrower country's debt-to-GDP ratio and macroeconomic volatility.

In explaining the cyclical movements of terms of trade, this paper is related to other studies in the international business cycle literature.[8] But many of them ruled out actual default events in equilibrium, unlike this model. Thus this paper is closely related to sovereign debt literature, especially to previous quantitative small-open-economy sovereign default models, such as those by Aguiar and Gopinath (2006), Arellano (2008), and Mendoza and Yue (2012), based on Eaton and Gersovitz (1981). They have made significant contributions to endogenizing default risk (with production), as well as to accounting for key empirical patterns of developing countries' business cycles and default episodes.

However, those above models do not focus on default-triggered changes to terms of trade. In particular, Mendoza and Yue (2012) have borrower-country firms import intermediate goods from a creditor country, and they impose a default penalty on the intermediate goods imports to generate a production efficiency loss in the defaulting country. This paper instead focuses on another type of vertical integration and efficiency loss: borrower-country firms exporting intermediate goods to the creditor country—its demand for the borrower's intermediate goods declines when default occurs. This mechanism is especially important compared to the one through intermediate imports, given that intermediate exports have been larger than intermediate imports for LA countries during the 1980s and at least as large in recently years. This mechanism is also complementary to what has already been studied by Mendoza and Yue (2012) and others, and thus fills the gap in the literature.

A few recent sovereign default papers (Cuadra and Sapriza (2006), Bleaney (2008), and Popov and Wiczer (2014)) have examined the roles of *exogenous* terms-of-trade shocks and *exogenous* terms-of-trade default penalty in small open economy models. The inclusion of endogenous terms of trade and real exchange rate distinguishes this paper from them. Na et al. (2018) also include endogenous exchange rate but focus on optimal exchange rate policy. Like the model in this

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paper, their model achieves concurrent default and depreciation. However, their depreciation is driven by wage rigidity and the government's intention to reduce unemployment, whereas this model's depreciation is associated with consumption home bias and changes to trade flows. Most recently, Asonuma (2014) has also endogenized the real exchange rate in a two-country sovereign default model, but through a different mechanism in endowment economies.[9] In this paper, I use production economies to incorporate richer business cycle fluctuations.

In addition, this paper complements the vast literature about international trade and financial crises with incomplete markets, especially for emerging economies (e.g., Mendoza (2002, 2010), Mendoza and Arellano (2003)). More specifically, it fits in the existing strand that focuses on the connection between international trade and exchange rate, and the strand on the connection between trade and sovereign defaults. In the former strand, this paper is related to works by Baldwin and Krugman (1989), Alessandria et al. (2010), Engel and Wang (2011), Drozd and Nosal (2012), and Alessandria et al. (2014). My model differs by endogenizing default risk in the bond interest rates.

In the latter strand of literature on trade and sovereign default, which consists largely of empirical studies, Rose (2005) documents that a default can reduce real bilateral trade value (in USD) by 8% for an extended period after the event. Asonuma et al. (2016) use panel data to confirm that both import and export decline and focus on the differential trade costs between preemptive debt restructuring and post-default restructuring. However, it remains unclear why trade declines. The four hypotheses—trade sanctions, trade credit collapse, asset seizures, and reputation—are commonly mentioned, but the empirical evidence supporting them remains ambiguous (Martinez and Sandleris (2011), Zymek (2012), and Tomz and Wright (2013)). One exceptional theoretical model is proposed by Bulow and Rogoff (1989), who apply creditors' seizures of a defaulting country's exports. This paper instead incorporates vertical exports and terms of trade to examine the interaction between trade and sovereign defaults. Moreover, it is important to note that there are theoretical models of trade flows during crises in general but they do not emphasize sovereign debt crises or have endogenous defaults, which distinguishes them from this paper. For instance, Gopinath and Neiman (2014) study the intermediate goods import collapse during Argentine 2001–2002 crisis in a non-sovereign-default model.

The remainder of this paper is organized as follows. Section 2 describes the theoretical model environment, equilibrium, and mechanisms. Section 3 provides the model calibration and quantitative results. Section 4 provides some empirical support to the efficiency loss that is emphasized in the model. Section 5 concludes.

2. MODEL

2.1. Environment

This section describes a dynamic model of two countries with endogenous sovereign default, terms of trade, real exchange rate, and risk averse agents. In

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the model, the two countries ($i = 1, 2$) trade a one-period discount bond, and each produces a unique final goods ($j = 1, 2$, respectively) and consumes both through trade. The two final goods are imperfect substitutes with constant elasticity, and c_{ij} stands for country i's consumption of final goods j. p_j stands for the final goods j's price. Country 1's final goods is the numeraire and its price p_1 is normalized to 1. I assume that the nominal exchange rate between the two countries is 1, and thus the real exchange rate is the ratio of country 2's over country 1's aggregate price index. When the ratio decreases, country 2 experiences real depreciation.

I set country 1 to be the creditor who never defaults and has constant productivity e_1; country 2 is the borrower who has an option to default on its sovereign bonds and faces stochastic productivity e_2 that follows a Markov chain.[10] Creditor country 1 has a fixed amount of capital, $\bar{k}_1$, which can be partially paired with a fixed amount of domestic labor $\bar{n}_1$ to produce the final goods 1, and partially with an imported intermediate goods produced by borrower country 2's labor to produce the same final goods 1. I use k_1 to denote capital used with domestic labor, k_m to denote that used with imported intermediate inputs, and hence $k_1 + k_m = \bar{k}_1$.[11] Borrower country 2 has a fixed amount of labor, $\bar{n}_2$. It is divided into n_m who produce intermediate inputs for creditor country 1, and $n_2 = \bar{n}_2 - n_m$ who produce final goods 2 with domestic capital $\bar{k}_2$.

Four reasons stand out for this model setup, where creditor country 1 allocates capital and borrower country 2 allocates labor and produces the intermediate goods for exporting. First, many of the countries that have recently defaulted are developing or emerging economies, where labor tends to be relatively abundant and is used to produce goods for exports (e.g., Bowen et al. (1987) and Schott (2003)).[12]

Second, sample countries used in this paper have been exporting intermediate goods more than or at least as much as they have been importing them. The earliest data from the World Bank show that Latin America and Caribbean countries exported 13.95 billion dollars intermediate goods to the rest of the world (1.89 billion to the USA) while importing 6.06 billion from the rest of the world (1.33 billion from the USA) in 1989. Since then the intermediate imports have been growing faster than the intermediate exports and their values became equally sizable during 2000s (e.g., 194.18 billion intermediate exports to the world and 65.23 billion to the USA while 196.23 billion intermediate imports from the world and 41.44 billion from the USA in 2010). Past literature has focused on the intermediate goods imports to the defaulting countries; however, the intermediate goods exports from those countries are just as important if not more.

Third, even though creditor country 1 does not produce intermediate goods, its labor and capital are imperfect substitutes for the imported intermediate goods and can be considered as creditor country 1's own implicit intermediate goods under a linear intermediate goods production technology. Similarly for borrower country 2, even though it does not use domestic intermediate goods for its own final goods production, but only for exporting, we can consider its domestic inputs as implicit intermediate goods.[13]

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Fourth, the impact of a sovereign default on the demand for borrower country 2's intermediate goods exports serves as one of the default penalties in the model. Even though the data show defaulting countries' intermediate goods *imports* are also usually reduced during crises (Mendoza and Yue (2012) and Gopinath and Neiman (2014)), I extract it from this paper because its inclusion would make it difficult to single out the impact of the intermediate goods export reduction upon default as a penalty, which is the focus of this paper. This paper does not intend to match with data perfectly but to study this mechanism through the intermediate goods export demand penalty. The current setup serves this purpose well.

Nevertheless, to compare this paper's mechanism with the impact of intermediate goods import channel, I solve an alternative model with a creditor country producing intermediate capital goods and a borrower country importing them to combine with its own domestic intermediate goods for final goods production (without the borrower country exporting intermediate goods). In that model, the defaulting country also suffers from output losses and declines in import and export values, but what is different is that the model generates terms of trade improvements because of the increase in the defaulting country's final goods price and the decline in its intermediate goods import price. That is, since the defaulter is at a low productivity level, it has low demand for intermediate goods imports. The result of terms-of-trade improvements during crises is contradictory to the data. It further shows that including both intermediate goods imports and exports would make it difficult to distinguish their opposite effects on terms of trade. The Online Appendix presents the alternative model setup and its key results.

In the baseline model in bond market, a non-state-contingent one-period bond denominated in the creditor country's final goods 1 is traded between the two countries. Notice that theoretically this paper considers the borrower country as a group of developing countries and emerging markets with correlated sovereign default risk (e.g., LA countries, or Euro zone peripheral countries). These countries' sovereign bonds are similar risky and the sovereigns can decide how much to issue according to the creditor-provided price schedule. That is, the borrower behaves like a small open economy in the bond market, while it behaves like a large open economy in the goods trade market.

The bond is denoted as b_i for country i's asset holdings. The borrower country's default can be triggered by negative productivity shocks and can happen along the equilibrium. The default probabilities are endogenous to debt holding and output production. Risk-averse creditors in country 1 are willing to offer debt contracts that in some states may result in a default by charging a high interest rate. Hence, equilibrium interest rates reflect the two countries' concerns about the default probabilities, as well as their consumption changes and risk aversion (Lizarazo (2013)).

The timing of this model is as follows. Both countries start off with initial sovereign bond assets. After they observe the current productivity shock, borrower country 2 decides whether to repay its debt. If it does not default, the

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sovereign chooses its bond issuance amount knowing the creditor's price schedule. If it defaults, both countries enter financial autarky and return with a certain probability, and creditor country 1 firms' operations that use the intermediate goods from borrower country 2 suffer from an efficiency loss.[14] Then accordingly, both countries reallocate their capital and labor. And last, production, trade, and consumption take place. The following sections describe the model specifications.

2.2. Country 1: Creditor

Creditor country 1 has two types of agents: final goods firms, and households.

2.2.1. Firms. Firms hire domestic workers n_1, rent capital from households, choose capital allocation $\{k_1, k_m\}$, and decide how many intermediate goods inputs to import from borrower country 2.[15] Firms' goal is to maximize their profits, taking wage w_1, capital rent r_1, and intermediate goods price p_m as given:

$$\Pi_1 = \max_{n_1, q_m, k_1, k_m} \left\{ e_1 n_1^{\alpha_1} k_1^{1-\alpha_1} - w_1 n_1 - r_1 k_1 + e_1 (\varepsilon q_m)^{\alpha_3} k_m^{1-\alpha_3} - p_m q_m - r_1 k_m \right\}. \tag{1}$$

The first three terms are the profit the firms gain from using domestic labor n_1 to produce final goods 1. The last three terms are the profit the firms gain from using intermediate inputs εq_m to produce final goods 1, after deducting intermediate goods costs and capital rents. ε symbolizes the firms' efficiency of operating with the intermediate goods from borrower country 2. When the borrower country is not in default, $\varepsilon = 1$. When the borrower country is in default, a small portion of its intermediate goods used by country 1's firms is lost in operation, while the firms' production with domestic inputs is not directly affected. More specifically, during default episodes $\varepsilon = \min(\epsilon \frac{\bar{e}_2}{e_2}, 1)$, where $0 < \epsilon < 1$ and $\bar{e}_2$ is borrower country 2's average productivity. This formulation has three indications.

First, the default-triggered efficiency loss lies only in the foreign operations of *creditor country 1's firms, not in defaulting country 2's firms*, given that the latter are already subject to the negative aggregate productivity shocks that trigger sovereign defaults. Hence, the model assumes that default events and efficiency losses in ε do not directly affect the supply of the intermediate goods. It is creditor country 1 firms' demand of the intermediate goods that is directly affected, in reality possibly due to defaulting country 2's worsened foreign business environment and/or crisis-elevated trade costs and information asymmetry that cause country 1 firms' marginal cost of operating with the imported intermediate goods to rise. The efficiency loss is consistent with a demand shock, which is the key to this model's mechanism. The mechanism, however, is not contingent upon the efficiency loss' negative impact on the creditor country. This setup has the virtue to endogenously generate default costs to the borrower country, without imposing exogenous default cost shocks to the defaulting country directly.

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Second, the efficiency loss is applied only to country 1 firms' production *using imported inputs from the defaulting country, not to their production using domestic inputs*, for which this paper provides empirical support in the later section. In the regression analysis, Brazil and Mexico are used as a group representing Latin America for the defaulting country and the USA for the creditor country. I collect US monthly output data on 14 manufacturing industries for the period from January 1981 to December 2012. After controlling for US nationwide trend and business cycles as well as industry-specific trends, I find statistically significant negative impacts of LA sovereign default episodes on US manufacturing outputs (a decrease of 0.7–4.3% below trend). More importantly, a US industry that uses more LA inputs is 0.1–0.5% more negatively affected by those default episodes than an industry that uses less such inputs.

Third, the formulation of ε generates efficiency losses and default penalties that increase with defaulting country 2's productivity state, such that, all else being equal, the borrower country has a larger incentive to default at a lower productivity state. This is consistent with previous sovereign default models (Arellano (2008)). Overall, without the efficiency loss, the transition dynamics from non-default regime to default regime would be much flatter.

2.2.2. Households. Households in creditor country 1 supply fixed amounts of capital $\bar{k}_1$ and labor $\bar{n}_1$ to the firms. They use the proceeds from firms for consumption to maximize a standard time-separable utility function $E[\sum_{t=0}^{\infty} \beta_1^t U(c_{11t}, c_{12t})]$, where $0 < \beta_1 < 1$ is the discount factor and $U(.)$ is a one-period utility function that is continuous, homothetic, strictly increasing, and concave, and satisfies the Inada conditions. More specifically, based on Krugman (1980), I use an additive separable utility function $U(c_{11t}, c_{12t}) = \rho_1 c_{11t}^{\theta_1} + (1 - \rho_1) c_{12t}^{\theta_1}$, where $0 < \rho_1, \theta_1 < 1$. The elasticity of substitution is constant at $\frac{1}{1-\theta_1}$. This utility function assumes independence between the domestic final goods and the imported final goods in marginal utility, and brings tractability and computability to this model.

Households also choose how many of the one-period non-state-contingent bonds issued by borrower country 2 to purchase, given the bond price q. Hence, their expected lifetime utility depends on borrower country 2's default decisions. When the borrower country does not default in the current period, the creditor country households' optimization problem can be written recursively as

$$V_{1c}(s, b_1) = \max_{b_1', c_{11}, c_{12}} \left\{ U(c_{11}, c_{12}) + \beta_1 [\int_{s' \notin \mathcal{D}(b_2')} V_{1c}(s', b_1') dF(s'|s) + \int_{s' \in \mathcal{D}(b_2')} V_{1d}(s') dF(s'|s)] \right\}, \quad (2)$$

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where b_i' is country i *tomorrow*'s bond asset holding, and s is the aggregate state of the two economies. F and $\mathcal{D}$ are the distribution for borrower country 2's productivity process and its default set, respectively, which I explain in the next section. The household problem is subject to

$$w_1\bar{n}_1 + r_1\bar{k}_1 + b_1 = c_{11} + p_2c_{12} + qb_1', \tag{3}$$

where $q = \beta_1 \frac{\int_{s'\notin\mathcal{D}(b_2')} \partial V_{1c}'/\partial b_1' dF(s'|s)}{\lambda_1}$, and λ_1 is the multiplier of the budget. Hence, q is the bond price schedule that country 1 provides to the borrower country 2.

The creditor country's constrained maximization problem becomes when the borrower country defaults:

$$V_{1d}(s) = \max_{c_{11},c_{12}} \{U(c_{11}, c_{12}) + \beta_1 E_1[\phi V_{1x}(s', 0) + (1-\phi)V_{1d}(s')]\}, \tag{4}$$

where $0 < \phi < 1$ is the probability of it resuming bond trading, and $V_{1x} = (V_{1d}(s)$ or $V_{1c,b_1}(s)|$borrower country 2 defaults or not). The problem is subject to

$$w_1\bar{n}_1 + r_1\bar{k}_1 = c_{11} + p_2c_{12}. \tag{5}$$

Given the above setup, I calculate creditor country 1's GDP as the gross production of final goods 1 minus the cost of the imported intermediate goods, that is, $e_1n_1^{\alpha_1}k_1^{1-\alpha_1} + e_1(\varepsilon q_m)^{\alpha_3}k_m^{1-\alpha_3} - p_mq_m$. Note that its GDP value and volume are the same in the model because its final goods price is $p_1 = 1$.

2.3. Country 2: Borrower/Defaulter

Country 2 has four types of agents: intermediate goods firms, final goods firms, households, and a government.

2.3.1. Intermediate goods firms. Intermediate goods firms produce intermediate goods inputs for creditor country 1 firms' final goods 1 production. They decide how many domestic workers to hire, n_m, and labor is the only input needed for the intermediate goods production. I assume the production to be linear in n_m and associated with the country's aggregate productivity e_2. The firms also pay labor wage w_m that is measured in final goods 2. They maximize the following profit:

$$\max_{n_m}\{p_me_2n_m - p_2w_mn_m\}. \tag{6}$$

Note that the supply of the intermediate goods is not directly affected by ε, even though the equilibrium quantity is. From the first-order condition, we have $p_m = \frac{p_2w_m}{e_2}$.

2.3.2. Final goods firms. Country 2's final goods firms rent capital k_2 and hire domestic workers n_2 to produce final goods 2. They maximize the following profit:

$$\max_{n_2,k_2}\{p_2e_2n_2^{\alpha_2}k_2^{1-\alpha_2} - p_2w_2n_2 - p_2r_2k_2\}, \tag{7}$$

where w_2 is domestic sector wage that is also measured in final goods 2.

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2.3.3. Households. Households in borrower country 2 supply labor $\bar{n}_2$ and capital $\bar{k}_2$. They derive income from two sources: wages from producing the intermediate goods for creditor country 1, and wages and capital rent from domestic final goods firms. Their utility is a standard time-separable homothetic function of a consumption bundle $E[\sum_{t=0}^{\infty} \beta_2^t U(c_{21t}, c_{22t})]$, where $0 < \beta_2 < 1$ is the discount factor. Similar to creditor country 1, the one-period utility function is specified as $U(c_{21t}, c_{22t}) = (1-\rho_2)c_{21t}^{\theta_2} + \rho_2 c_{22t}^{\theta_2}$, where $0 < \rho_2, \theta_2 < 1$. The elasticity of substitution is constant at $\frac{1}{1-\theta_2}$. As in Mendoza and Yue (2012), households do not borrow directly from abroad, but the government chooses a debt policy internalizing the utility of households, taking as given the wages and the capital rent.

2.3.4. Government. Country 2's sovereign government issues one-period non-state-contingent discount bonds, so the asset market is incomplete. It cannot commit to repaying its debt; it compares the value of repaying debt V_{2c} and that of default V_{2d} and chooses the option that provides a greater value, that is,

$$V_{2x}(s, b_2) = \max\left\{V_{2c}(s, b_2),\, V_{2d}(s)\right\}. \qquad \textbf{(8)}$$

The nondefault value is given by the choice of (b_2', c_{21}, c_{22}) that maximizes the following problem, taking wages, capital rent, p_2, and bond price q as given:

$$V_{2c}(s, b_2) = \max_{b_2', c_{21}, c_{22}} \left\{ U(c_{21}, c_{22}) + \beta_2 \Big[\int_{s' \notin \mathcal{D}(b_2')} V_{2c}(s', b_2') dF(s'|s) + \int_{s' \in \mathcal{D}(b_2')} V_{2d}(s') dF(s'|s) \Big] \right\}, \qquad \textbf{(9)}$$

subject to

$$p_2 w_2 n_2 + p_2 r_2 \bar{k}_2 + p_2 w_m n_m + b_2 = c_{21} + p_2 c_{22} + q b_2', \qquad \textbf{(10)}$$

where F and $\mathcal{D}$ are the sovereign's productivity process and default set, respectively. $q = \beta_1 \frac{\int_{s' \notin \mathcal{D}(b_2')} \partial V_{1c}' / \partial b_1' dF(s'|s)}{\lambda_1}$ is from creditor country 1's problem.

In the event of a default triggered by an adverse productivity shock to the borrower country, the foreign demand for the defaulting country's intermediate goods declines due to an efficiency loss in foreign firms' operations with those imported inputs. Meanwhile, both countries enter financial autarky as their bond assets are set to zero, and return to bond trading with probability $0 < \phi < 1$. There is no other direct penalty, such as exogenous endowment loss or trade sanctions.[16] However, in equilibrium the defaulting country does suffer other endogenous losses, as I will discuss in the mechanism Section 2.4.1. Taking into account all the consequences of a sovereign default, the borrower country's default value is as follows:

$$V_{2d}(s) = \max_{c_{21}, c_{22}} \{U(c_{21}, c_{22}) + \beta_2 E_2[\phi V_{2x}(s', 0) + (1-\phi) V_{2d}(s')]\}, \qquad \textbf{(11)}$$

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subject to

$$p_2 w_2 n_2 + p_2 r_2 \bar{k}_2 + p_2 w_m n_m = c_{21} + p_2 c_{22}. \qquad (12)$$

The definitions of the actual default set $\mathcal{D}$ and the actual probability of default are standard from Eaton–Gersovitz-type models (also see Arellano (2008)). Default set $\mathcal{D}$ at each current debt level b_2 is a collection of exogenous states when borrower country 2's government strategically chooses to default to maximize its value:

$$\mathcal{D}(b_2) = \{s \in S : V_{2c}(s, b_2) < V_{2d}(s)\}. \qquad (13)$$

Because no one can be certain about the aggregate state tomorrow, the actual default probability π is the sum of all the probabilities of tomorrow's states where the borrower country will choose to default, given the debt level:

$$\pi(s, b_2') = \int_{s' \in \mathcal{D}(b_2')} f(s, s') ds'. \qquad (14)$$

Given the above setup, I calculate borrower country 2's GDP value as the gross production of final goods 2 plus the intermediate goods exports, $p_2 e_2 n_2^{\alpha_2} k_2^{1-\alpha_2} + p_m e_2 n_m$, and its GDP volume as $e_2 n_2^{\alpha_2} k_2^{1-\alpha_2} + e_2 n_m$.

2.4. Equilibrium

Finally, in equilibrium all goods, capital, labor, and bond markets clear for both countries in default and nondefault regimes. Also, in the borrower country, the intermediate goods sector per-worker wage is equal to the wage paid in its domestic production sector, so that there is no labor flowing between the two sectors. The equilibrium conditions are formulated and defined as follows:

$$b_1'(s, b_1) + b_2'(s, b_2) = 0 \quad \text{in nondefault regime,} \qquad (15)$$

$$\text{or} \quad b_1'(s, b_1 = 0) = 0 \quad \& \quad b_2'(s, b_2 = 0) = 0 \quad \text{in default regime,} \qquad (16)$$

$$\text{and} \quad n_1 = \bar{n}_1, \quad k_1 + k_m = \bar{k}_1, \quad n_2 + n_m = \bar{n}_2, \quad k_2 = \bar{k}_2, \quad w_m = w_2, \qquad (17)$$

$$e_1 n_1^{\alpha_1} k_1^{1-\alpha_1} + e_1 (\varepsilon q_m)^{\alpha_3} k_m^{1-\alpha_3} = c_{11} + c_{21}, \quad e_2 n_2^{\alpha_2} k_2^{1-\alpha_2} = c_{12} + c_{22}, \quad e_2 n_m = q_m. \qquad (18)$$

Definition 1. *A recursive equilibrium is defined as a set of functions for (a) creditor country 1's capital allocation and borrower country 2's labor allocation; (b) both countries' household consumption policy c and saving policy b'; (c) price function for bonds $q(b_2, s)$; (d) welfare value V at default and nondefault regimes; and (e) the law of motion for the aggregate state s, such that (i) taking as given the borrower country's policies, firms' working capital, and labor decisions, as well as households' consumption, satisfy both countries' optimization problems and the world resource constraint so that r_1, r_2, p_m, and p_2 clear the capital and goods markets, and w_m and w_2 stabilize labor flows between the two sectors in borrower*

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country 2; (ii) taking as given the bond price function $q(b_2, s)$, the borrowing and lending policies and default sets satisfy both countries' optimization problems; (iii) bonds prices $q(b_2, s)$ reflect the government's default probabilities and are consistent with the creditor country's optimization problem; (iv) the law of motion is consistent with the stochastic processes of e_2.

Borrower country 2's terms of trade and real exchange rate are calculated using Laspeyres price index.[17] More specifically, they are calculated as follows:

$$TOT_{2t} = \frac{(p_2^t c_{12}^0 + p_m^t q_m^0)/(c_{12}^0 + q_m^0)}{p_1^t c_{21}^0 / c_{21}^0}, \quad (19)$$

$$REXR_{2t} = NEXR \frac{(p_2^t c_{22}^0 + p_1^t c_{21}^0)/(p_2^0 c_{22}^0 + p_1^0 c_{21}^0)}{(p_2^t c_{12}^0 + p_1^t c_{11}^0)/(p_2^0 c_{12}^0 + p_1^0 c_{11}^0)}. \quad (20)$$

2.4.1. Mechanism. This section explains the important mechanisms in this model. First of all, *prior to a default*, how is default risk linked with trade and the terms of trade? As the borrower country accumulates debt, its default risk and the equilibrium bond interest rate rise. The higher cost of debt reduces the borrower country's available funds for consumption relative to the creditor country's; thus, owing to consumption home bias in both countries, the world relative demand of final goods 2-to-1 decreases.[18] Decreasing relative demand of final goods 2-to-1 puts downward pressure on the relative price p_2, preventing the borrower country from improving terms of trade to ease its budget constraint and debt burden. Hence, when higher default risk rises, the terms of trade deteriorate, and in turn, this deterioration increases the borrower country's default risk.

Once a large enough adverse productivity shock causes borrower country 2 to default, the mechanism affecting income, trade, and terms of trade works as follows. The default triggers an efficiency loss to the creditor country firms' operations using the defaulting country's intermediate goods, which has several effects. First, the demand of the intermediate goods declines, resulting in a lower p_m. Second, creditor country 1's firms have to reallocate capital away from combining with the imported intermediate goods, and toward its domestic labor to produce final goods 1. This decreases creditor country 1's marginal product of capital, as well as its capital rents.

Third, in the defaulting country 2, fewer workers are hired in the intermediate goods sector, so some workers have to shift to domestic production of final goods 2, since this model has no unemployment.[19] The labor shifting enables the defaulting country to produce and export more of its own final goods 2 despite the initial adverse productivity shocks than the country would be able to without such labor shifting. In addition, the lower demand for labor and the overflow of workers into the domestic goods sector lowers the defaulting country's wage in *both* sectors.[20] The reduced labor income contributes to the sovereign default costs.

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Overall, owing to the initial adverse productivity shock and the additional wage reduction, the defaulting country's income declines even though it does not repay the debt. When its available funds for consumption declines relative to the creditor country's, the world relative demand of final goods 2-to-1 decreases, again because of two countries' home bias preferences in consumption. Therefore, the defaulting country's terms of trade and real exchange rate deteriorate, which in turn induces more losses to its income, purchasing power, and trade values. Without the efficiency loss, the transition dynamics from non-default regime to default regime would be much flatter.

In particular, from both countries' households' first-order conditions (equation (21)) and budget constraints, we can see how the defaulting country's wealth share in the world affects the world relative demand of final goods 2-to-1 (*RD*, equation (22)):

$$p_2 = \frac{\rho_2}{1-\rho_2}(\frac{c_{21}}{c_{22}})^{1-\theta_2}, \quad p_2 = \frac{1-\rho_1}{\rho_1}(\frac{c_{11}}{c_{12}})^{1-\theta_1}, \tag{21}$$

$$RD \equiv \frac{c_{12}+c_{22}}{c_{11}+c_{21}} = \frac{S_2(\frac{1}{g_2}-\frac{1}{g_1})+\frac{1}{g_1}}{1-\frac{p_2}{g_1}+S_2(\frac{p_2}{g_1}-\frac{p_2}{g_2})}, \tag{22}$$

where $S_2 = \frac{GDP_2+b_2-qb_2'}{GDP_1+GDP_2}$ is the wealth share of borrower country 2 in the world, $g_1 = (\frac{p_2\rho_1}{1-\rho_1})^{\frac{1}{1-\theta_1}} + p_2$, and $g_2 = [\frac{p_2(1-\rho_2)}{\rho_2}]^{\frac{1}{1-\theta_2}} + p_2$. If the two countries' households have exactly the same preferences toward the two final goods, that is, $g_1 = g_2$, then the world wealth share has no effect on the world relative demand. In this model, because there is home bias in both countries making $g_1 > g_2$, all else being equal, the world demand of final goods 2 (i.e., $c_{12} + c_{22}$) is positively related to S_2, while that of final goods 1 (i.e., $c_{11} + c_{21}$) is negatively related to S_2. Therefore, the world relative demand of final goods 2-to-1, *RD*, increases with borrower country 2's wealth share in the world S_2. The above is generalized in the following proposition.

PROPOSITION 1. *(1.1) If $g_1 > g_2$, then all else being equal the world relative demand of final goods 2-to-1, RD, is positively related to borrower country 2's wealth share in the world S_2, that is, $\frac{\partial RD}{\partial S_2} > 0$. (1.2) In other words, if the sum of the two countries' home goods expenditure shares is strictly larger than 1, that is, $\frac{c_{11}}{GDP_1+b_1-qb_1'} + \frac{c_{22}p_2}{GDP_2+b_2-qb_2'} > 1$, then all else being equal $\frac{\partial RD}{\partial S_2} > 0$.*

Proof. See Online Appendix. ■

As default risk increases or during default episodes, borrower country 2's wealth share in the world declines, which causes the world relative demand of final goods 2-to-1 to decrease. This reduces the relative price of final goods 2, p_2, and borrower country 2's real exchange rate.[21] Together with lower p_m, its terms

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of trade also deteriorate. This mechanism becomes stronger as g_1 increases, or g_2 decreases, that is, as either country becomes more home biased in consumption.

PROPOSITION 2. *When* $g_1 > g_2$, $\frac{\partial RD}{\partial S_2}$ *increases with* g_1 *and decreases with* g_2.

Proof. See Online Appendix. ■

From equation (21), we can also see that as p_2 decreases when default risk increases or during default episodes, borrower country 2's consumption shifts toward the home goods (i.e., $\frac{c_{21}}{c_{22}}$ declines), while creditor country 1's shifts toward the foreign goods (i.e., $\frac{c_{11}}{c_{12}}$ declines). Hence, trade flows change.

To summarize, the main costs to the creditor when the borrower defaults are the missed debt repayment, and the production loss caused by an efficiency loss in using imported intermediate inputs from the defaulting country. These constrain the creditor country's budget. However, the creditor gains from more favorable terms of trade and real appreciation that allow it to import more of the borrower country's final goods. For the borrower country, the main costs upon default are wage losses, lower purchasing power, and no access to the international bond market for consumption smoothing. It gains by forgoing the debt repayment.

3. QUANTITATIVE RESULTS

3.1. Baseline Calibration

In this section, I study the quantitative implications of the model by conducting numerical simulations at the quarterly frequency, and using a baseline calibration based on data from LA countries and the USA, Table 1 shows the calibrated parameter values.[22]

The probability that both countries reenter the international financial market after a default is 0.083, which implies that the borrower country stays in exclusion for an average of 3 years after default. This is the estimate obtained by Richmond and Dias (2009) for the median duration of exclusion periods. It is also consistent with the finding by Gelos et al. (2011) and is applied by Mendoza and Yue (2012).

The parameters ρ_1 and ρ_2 in the model control the degree of home bias in consumption. According to the World Bank (WDI), the average share of domestic products in final consumption for the USA and Latin America for the period 1981–2012 is 0.85 and 0.8, respectively. Hence, I use Latin America's 0.8 in calibrating ρ_2 such that, at steady state, borrower country 2's domestic goods share in final consumption is about 0.8. As for the USA, not all 15% of its final consumption is from Latin America. Since Latin America accounts for on average 14% of USA imports over the same sample period, I calibrate ρ_1 such that, at steady state, creditor country 1's domestic goods share in final consumption is 0.97.

The next two parameters θ_1 and θ_2 have to do with the elasticity of substitution between domestic goods consumption and imported goods consumption for developed and developing countries.[23] The literature provides a large range of estimates for the elasticity of substitution. Backus et al. (1994) document that US

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TABLE 1. Parametrization

Calibrated parameter	Value	Target statistics
Bond market re-entry probability	$\phi = 0.083$	Dias and Richmond (2007)
Creditor country 1 home bias	$\rho_1 = 0.86$	0.97, US consumption share of non-LA goods
Borrower country 2 home bias	$\rho_2 = 0.90$	0.80, LA home goods consumption share
Creditor country 1 elasticity of substitution	$\theta_1 = 0.25$	1.33, advanced economy intratemporal elasticity
Borrower country 2 elasticity of substitution	$\theta_2 = 0.60$	2.50, emerging economy intratemporal elasticity
Creditor country 1 domestic production labor share	$\alpha_1 = 0.63$	From OECD data for US
Borrower country 2 domestic production labor share	$\alpha_2 = 0.45$	From ILO estimates for LA
Intermediate goods share in final goods 1 production	$\alpha_3 = 0.54$	US and LA average labor share in production
Creditor country 1 labor endowment	$\bar{n}_1 = 1$	Normalized to 1
Creditor country 1 capital endowment	$\bar{k}_1 = 9.59$	0.15, average FDI Stock-to-GDP ratio for LA
Borrower country 2 labor endowment	$\bar{n}_2 = 1$	1, average LA-to-US employment ratio
Borrower country 2 capital endowment	$\bar{k}_2 = 2$	0.2, average LA-to-US capital stock ratio
Creditor country 1 productivity	$e_1 = 4.20$	0.5, average LA-to-US GDP ratio
Borrower country 2 productivity steady state	$E(e_2) = 1$	Normalized to 1
Borrower country 2 autocorrelation of TFP	$\rho = 0.42$	From production function
Borrower country 2 std. dev. of TFP shocks	$\sigma = 0.04$	From production function
Creditor country 1 discount factor	$\beta_1 = 0.99$	1%, US government bond interest rate
Parameter by simulation	**Value**	**Target statistics**
Borrower country 2 discount factor	$\beta_2 = 0.70$	2%, quarterly default frequency for LA
Intm. goods sector efficiency loss upon default	$\epsilon = 0.85$	−0.18, average intm. goods export income deviation from trend upon default for Mexico

elasticity is between 1 and 2; valuesin this range are commonly used in empirical trade models. Their benchmark model adopts a value of 1.5. Later authors have used similar values, for example, Chari et al. (2002), Bergin (2006), and Ruhl

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(2008). A recent paper by Feenstra et al. (2014) also finds point estimates for the macro elasticity exceeding unity in almost all industries.

However, few papers have studied the Armington elasticity for developing countries. Ostry and Reinhart (1992) find the elasticity of substitution between *traded* and *nontraded* goods in the range of 1.22–1.27, and significant regional differences, with less-developed countries displaying higher values. Yet, the cross-country comparison of Armington elasticities remains unclear. This paper does not take a stand on the value of the elasticity. As a starting point, I adopt 1.33 as the elasticity of substitution for the creditor country to match that for developed countries on average, and a higher value of 2.5 for the borrower country to indicate that less-developed countries may have a higher elasticity of substitution between *home* and *foreign* goods as they do for traded and nontraded goods.

The labor share in the final goods production is set at 0.63 for the USA and 0.45 for Latin America. The latter statistics is consistent with ILO estimates (Lubker (2007)). The input share of imported intermediate goods to produce final goods 1 (α_3) is the average labor share in final goods production of the USA and Latin America. I vary this parameter value in comparative analyses to examine the effect of vertical export.

The capital endowment of borrower country 2 is set such that the country has about one fifth of the creditor country 1's capital stock, as it is the case between Latin America and the USA. The labor endowment of both countries is fixed at 1, and thus it matches the average ratio of major LA countries' employment to the US employment for 1981Q1–2012Q4 and LA countries are relatively more labor abundant than the USA.[24] Creditor country 1's capital endowment $\bar{k}_1$ is chosen such that, at steady state, its capital used with the intermediate goods, k_m, is about 15% of borrower country 2's GDP. This is approximated by the average of FDI stock-to-GDP ratio for Latin America during the same sample period, assuming the majority of the FDI is vertical. However, it is important to note that this approximated target is by no means a complete calibration for the actual amount of foreign capital used with LA intermediate goods to produce foreign final goods.

The only productivity shock in the model is to borrower country 2's productivity e_2, whose steady state is normalized to 1. It follows an AR(1) process

$$\log e_{2,t} = \rho \log e_{2,t-1} + \eta_t,$$

with η being iid and following $N(0, \sigma^2)$. Using the method proposed by Tauchen and Hussey (1991), I construct a Markov approximation to this process for e_2. For creditor country 1, its constant productivity e_1 is calibrated to be 4.2, so that at steady state the creditor-to-borrower GDP ratio is 0.5, equal to the average LA-to-US GDP ratio for 1981–2011, according to IMF annual data. Due to data limitation for some LA countries, I estimate the process using the model's production functions, and HP-filtered Mexican GDP (average), capital stock, and employment in both the domestic sector and the FDI sector for 1981Q1–2012Q4.

US treasury bills bear real interest rates that are below 1% on average, hence we have $\beta_1 = 0.99$. Last, the targets for setting β_2 and ϵ are quarterly frequency

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of LA defaults and the loss in its intermediate goods exports upon default. I set the quarterly default frequency at about 2%, which is consistent with the default frequency for the major LA countries collectively. For instance, Mexico had eight default episodes between 1828 and 2012 according to Reinhart (2010). Argentina, Brazil, Chile, and Peru also had similar amount of (overlapping) episodes in the same period. For the loss in borrower country 2's intermediate goods exports, I use Mexican data due to data availability limitation for other LA countries. At the onset of these most recent sovereign default episodes, Mexico's intermediate goods export value, on average, was about 18% below trend. Given these two targets, the simulated procedure yields $\beta_2 = 0.70$ and $\epsilon = 0.85$. The low value of β_2 is due to the high default frequency in LA countries collectively and the significant default costs from the terms of trade deterioration.

In the following sections, I first examine the properties of the calibrated model, then study the simulated results both over business cycles and around default events, and then examine the impacts of the efficiency loss, vertical export, and consumption home bias in comparative analyses.

3.2. Policy Functions

The properties of bond quantity and its price in the baseline model are in line with other sovereign default papers, as shown in Figure A.1 in the Online Appendix. Here I focus on the policy functions for trade prices and flows in Figure 1. The sloped portion is the policy function when the borrower does not default, the flat portion is when it defaults and is indirectly affected by the efficiency loss.

Top two subplots graph the borrower's terms of trade (left) and real exchange rate (right) against its current assets, in a high-productivity state (dash line) and a low-productivity state (solid line). As the sovereign accumulates debt (to the left of the bottom axis) and default risk increases, its terms of trade and real exchange rate deteriorate. The deterioration is more severe when the borrower defaults at a high-productivity state than at a low-productivity state, because the efficiency loss is larger in the former state than in the latter. Such larger loss prevents the borrower from defaulting during the high-productivity state, as in Arellano (2008). It is also clear from the policy functions that without the efficiency loss, the policy function changes from non-default regime to default regime would be much less drastic.

The subsequent plots in Figure 1 graph various trade flow functions. Notice that all trade values are denominated in country 1's goods. They show that, across productivity states, trade flows are in general higher for a high-productivity state than for a low-productivity state, which implies that trade flows are procyclical. Moreover, imports decrease with the debt level, while exports increase with it until a default occurs. When the borrower accumulates debts at a high-productivity state and then defaults once its productivity becomes low, imports will decline sharply while final goods export volume may increase (second row), due to the efficiency loss and the deterioration in terms of trade and real exchange

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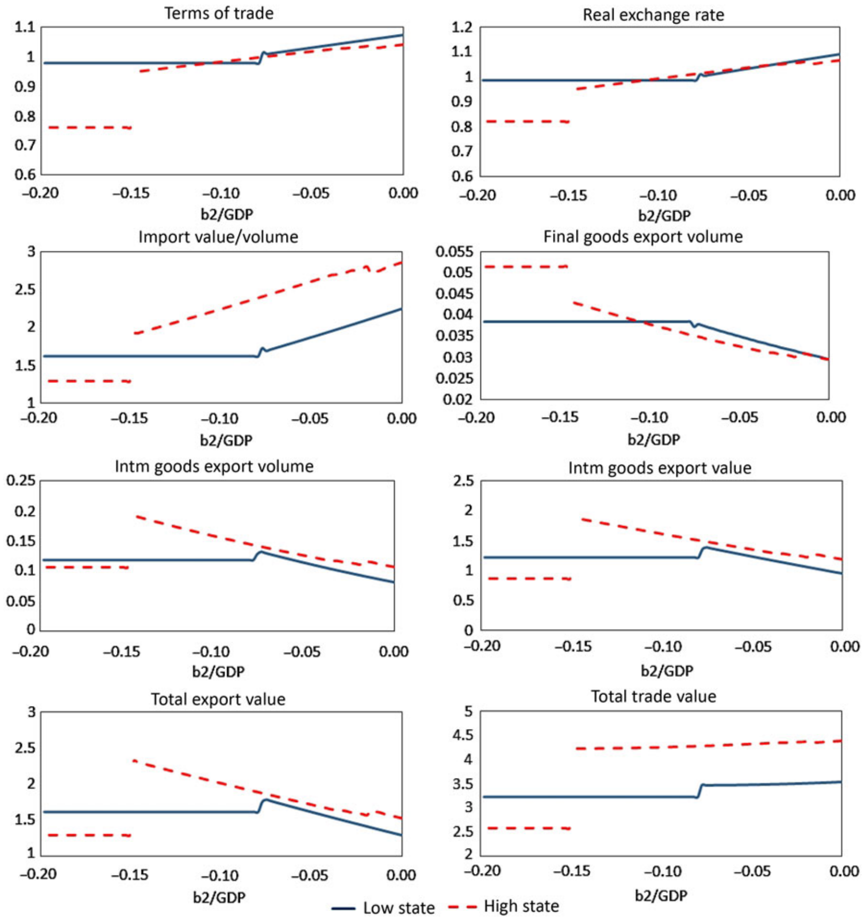

FIGURE 1. Trade price policy functions.

rate. Meanwhile, in contrast to final goods export volume, intermediate goods export volume will decrease (third row). This is because of the efficiency loss that lowers the demand for the defaulter's intermediate goods. These policy functions generate data-consistent trade-volume dynamics around default events as I show in Figures 3 and 4 later. Combining volume and price changes, export value, import value, and total trade value all decline upon default. These effects are important in generating trade flow dynamics in the next sections.

3.3. Cyclical Movements

This section starts the assessment of the qualitative and quantitative performances of the model by comparing moments from the data with moments from the model's dynamics. It is worth noting that this paper does not aim to match the

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data because many key elements in reality are extracted from the model. The goal is to study the mechanisms in such a model with default risk, goods trade, consumption home bias, and vertical export, and to examine how default risk and events, income, trade, and terms of trade interact with each other. Now, to compute statistical moments from the model's dynamics, I feed borrower country 2's productivity process into the model and conduct 500 simulations, each with 600 periods. Then I truncate the first 100 observations and use the rest to compute the statistics of the model results.

Table 2 compares the moments produced by the baseline model with those from data and from Mendoza and Yue (2012). In the data column, I choose to use Mexican data instead of other LA data, because it has better data quality and more availability over the time period under study and over intermediate trade, employment, and FDI. All the data used in this model are quarterly from 1981Q1 to 2012Q4. The data sources are provided in the Appendix. Note that Mendoza and Yue (2012) also calibrate their model partially to Argentine data and partially to Mexican data.

Table 2 shows that this model produces a debt-to-GDP ratio of about 6% on average, while matching the 2% default frequency observed in the data. The result that the debt-to-GDP ratio is lower than the data is common in the literature of strategic sovereign default models. There are several main factors impacting this ratio in the model, including the two countries' discount factors, sovereign default costs, and risk aversion. In particular, risk aversion limits this model's ability to generate data-matching debt-to-GDP ratios (Lizarazo (2013)). However, it does help my model support a high average bond spread, on which I elaborate below.

Model statistics for bond spreads are tricky in that during default periods the model has no finite interest rate. I report in Table 2 the modeled bond spread statistics for business cycles, with the infinite interest rates during default episodes being removed. The mean of bond spreads is relatively high. Here, the bond price reflects not only the expected return due to the probability of default, but also compensation to risk-averse creditors for bearing consumption risk. On average about a third of the interest rate is attributed to the risk premium from creditor's risk aversion.[25] The impact of risk aversion on the risk premium decreases relative to the impact of default risk as the borrower country approaches a default. Therefore, unlike many previous studies using small open economies with risk-neutral investors, this model breaks the close link between the probability of default and bond pricing by including the creditor country's welfare loss and risk aversion. Meanwhile, the modeled volatility of bond spreads is in between that of the data and that of Mendoza and Yue (2012).

In the model, the volatility of terms of trade is closer to the data than the volatility of real exchange rates is. When default risk increases or during default episodes, even though the borrower country's terms of trade deteriorate and its CPI declines, the creditor country also adjusts its consumption toward the cheaper imported final goods. It results in a lower CPI for the creditor country as well, causing the borrower country's real exchange rate does not decline as much as

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TABLE 2. Statistical moments of borrower country 2's business cycles

Statistics	Data	Baseline	M&Y
Average debt/GDP ratio (%)	74.94	6.16	22.88
Average bond spreads (%)	4.35	7.92	0.74
Bond spreads std. dev. (%)	4.71	2.32	1.23
Real exchange rate std. dev. (%)	17.30	3.33	*n.r.*
Terms of trade std. dev. (%)	6.21	4.53	*n.r.*
Dom. product con. std. dev./GDP std. dev.	1.23	1.01	*n.r.*
Total consumption std. dev./GDP std. dev.	1.12	1.05	1.05
Trade balance/GDP std. dev. (%)	2.08	1.04	*n.r.*
Correlation with GDP			
Bond spreads	−0.39	−0.70	−0.17
Real exchange rate	0.53	0.39	*n.r.*
Terms of trade	0.25	0.40	*n.r.*
Trade balance/GDP	−0.65	−0.27	−0.54
Total exports	0.21	0.67	*n.r.*
Intermediate goods exports	0.18	0.68	*n.r.*
Total import	0.75	0.86	*n.r.*
Wage	0.65	0.84	*n.r.*
GDP volume	0.65	0.81	*n.r.*
Default occurrence	−0.14	−0.23	−0.09
Correlation with bond spreads			
Real exchange rate	−0.76	−0.65	*n.r.*
Terms of trade	−0.13	−0.70	*n.r.*
Trade balance/GDP	0.30	0.07	0.15
Total exports	−0.02	−0.76	*n.r.*
Intermediate goods exports	−0.08	−0.79	*n.r.*
Total import	−0.28	−0.79	*n.r.*
Wage	−0.35	−0.41	*n.r.*
GDP volume	−0.19	−0.33	*n.r.*
Default occurrence	0.18	0.26	*n.r.*

Note(s): All data in the table are HP-filtered, except bond spreads and default occurrence. All data are in real terms and at quarterly frequency. Bond spreads are calculated over US government bond real interest rates that are sometimes negative. I use Laspeyres price index for CPI, real exchange rates, and terms of trade. *n.r.* stands for not reported.

its terms of trade do. Meanwhile, in the data, both the terms of trade and the real exchange rate are influenced by many other factors during business cycles, such as policies in trade, money supply, and nominal exchange rate, which this model does not take into account.

Domestic goods consumption is smoother in the model than in the data because of borrowing, home bias preference, and labor movement from the intermediate goods sector to the domestic sector during default crises. These three factors support domestic goods production and consumption in spite of adverse productivity shocks. Total consumption is less smoothed than domestic goods consumption in

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the model on account of the variations in imports and terms of trade over business cycles. It is also slightly more volatile than output, consistent with the data. The volatility of trade balances is lower in the model than in the data. Other sovereign default models have generated similar results. For example, Aguiar and Gopinath (2007) produce a trade balance standard deviation of 0.95, Arellano (2008) 1.5, and Yue (2010) 2.81.

Next, Table 2 shows that the correlation between GDP value and bond spreads, as well as their correlations with other macroeconomic and trade variables. It yields a negative correlation between bond spreads and GDP, consistent with the data, because bonds have a higher default risk in bad states. As in Mendoza and Yue (2012), this model produces countercyclical default risk in a setting where both income and default risk are endogenous and affect each other, unlike in the models of sovereign default alone or of business cycles alone.

However, this model distinguishes itself from Mendoza and Yue (2012) in that the endogenous income and default risk interact through the movement of terms of trade. In my model, both the terms of trade and the real exchange rate have a positive relation to GDP and a strong negative relation to bond spreads, which is consistent with the data. As explained in the model mechanism section, when the borrower country accumulates debt, the default risk and the interest rate rise, resulting in the country's terms-of-trade deterioration. This prevents real appreciation from easing its budget constraint and from helping it to pay back debt that is denominated in the creditor country's final goods. Therefore, default risk is further elevated to raise the bond interest rate. Once an adverse productivity shock causes the borrower country to default, the country is penalized by an additional income loss from a wage decline, causing its terms of trade and real exchange rate to deteriorate sharply. This takes another toll on the defaulting country's income.

More importantly, the model also delivers procyclical *trade flows* and a negative relation between trade flows and bond spreads consistently with the data, which have not been captured by previous sovereign default models. During downturns, the value of both imports and exports declines. The former is due to import volume decreases, and the latter is due to the terms of trade deterioration and the intermediate goods export volume decline. Meanwhile, the value of imports are more procyclical than that of exports in both data and the model result. Thus, this model also generates countercyclical trade balances, while producing a positive relation between the trade balances and bond spreads.

Furthermore, the model predicts a correlation between the borrower country's exported intermediate goods and its GDP or bond spreads, qualitatively in line with the correlations observed in the data. More broadly, it is not just Mexico that has a positive correlation between output and intermediate goods export value, many countries do. For instance, using annual growth data (1988–2013), I compute the correlation for 16 countries for which I have intermediate goods export data. On average across countries, the correlation between output growth and intermediate goods export growth is 41%.[26]

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As discussed earlier, the wage in borrower country 2 declines with productivity and even more so during sovereign default episodes. It is confirmed by the model results, where the wage strongly positively correlates with GDP and negatively with bond spreads, as in the data and the findings of Li (2011).

In addition, this model disentangles the default-related loss of GDP volume in GDP value. In Table 2, even though GDP value is positively correlated with GDP volume, it is not a perfect correlation—only 65% in the data and 82% in the model. The real exchange rate and terms of trade do play a role in explaining GDP value changes in both the model and the data. Also, consistent with the data, the model generates declining GDP volume when bond spreads increase over business cycles.

Last, I report in Table 2 the correlations between default and output, and between default and bond spreads. In particular, the onset of a default event is negatively correlated with output and positively correlated with bond spreads in both the data and the model.

3.4. Dynamics around Default Events

Next I study the baseline model's macroeconomic, trade, and welfare dynamics of borrower country 2 *around default events* by comparing the simulated results with the time series data for Mexico, as well as with the time series data for a list of LA countries that have defaulted since 1980 (see the Appendix for the list of countries).[27] I plot each episode window of six quarters before and after the onset of a default. Date 0 is the quarter in which the default occurs. I plot the mean of default episodes for each variable from the data, as well as the mean from the model simulation surrounded by a one-standard-deviation band.[28]

3.4.1. Macroeconomic dynamics. Figure 2 shows the model's macroeconomic dynamic results (dash lines), that is, deviations from the steady state of borrower country 2, compared with Mexican data (solid line) and the mean of all LA sample countries (dot-dash line). In the top left panel, the model generates a sharp decline (11% below trend) and a slow recovery of GDP value (measured in creditor country 1's final goods 1) that match well with those of the real GDP value data (in USD) for Mexico and other sample countries on average.

In the top right panel, on average the terms of trade are below its trend during and after a default in the model, which is consistent with the data. But the data also show a deeper decline (for Mexico) and a faster recovery than the model results, which may be improved in future research.

The bottom left panel of Figure 2 shows that the relative quantity of final goods 2-to-1 decreases around default in the equilibrium in the baseline model. Combining this result with terms of trade deterioration, we can deduct that the cause must be a decline in the world relative demand of final goods 2-to-1, consistent with the explanation in the mechanism section.

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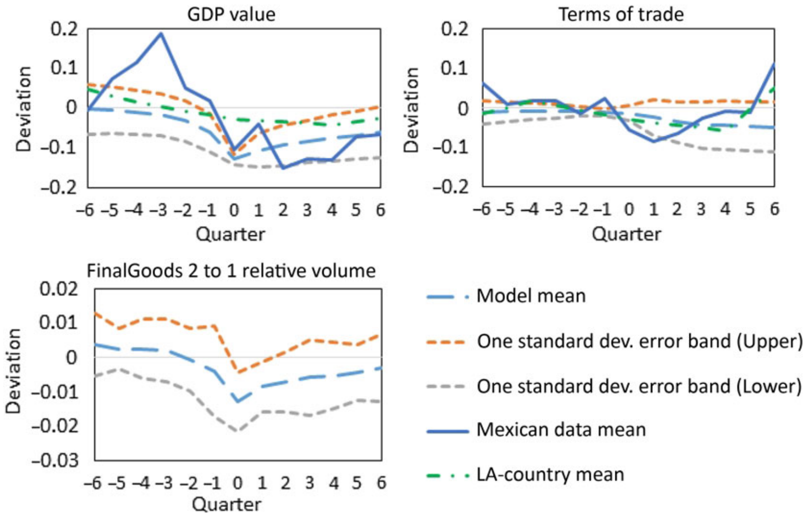

Note: All data are real and HP-filtered. GDP value (in USD) and terms of trade are logged before being detrended. The model results for GDP value are measured in creditor country 1's final goods 1.

FIGURE 2. Macroeconomic dynamics of borrower country 2 around default events.

3.4.2. Trade dynamics. Now I analyze the model's results for variables related to international trade (both volumes and values) around default events. Dynamics on trade volumes are reported in Figure 3. We can see that during default periods, final goods export volume increases, while intermediate goods export volume and import volume decrease in the data. One thing to note is that around $t = -3$ there is a significant decline in final goods export volume and an increases in import volume. Those irregularities are due to rises in Mexico's nominal exchange rate growth in 1982, 1985, and 1988. Since nominal exchange rate changes are not included to this model, this paper cannot take account of those events.

Disregarding these irregularities, the model captures the qualitative empirical features of the trade volume data during default periods. In particular, final goods import volume declines much more than the final goods export volume; in fact the latter has a slight increase, consistent with the data. The intermediate goods export volume declines as much as import volume does. Hence, the total goods export volume decline is not as much as the import volume decline.

Dynamics on trade values are reported in Figure 4. In the model, borrower country 2's total export value (measured in creditor country 1's final goods) declines, but more than data do. Most of the total export value declines come from intermediate goods exports (not final goods exports), which is true for both the model and the data (for Mexico and across LA countries). It is worth noting that the intermediate goods export value decline is targeted by the model during

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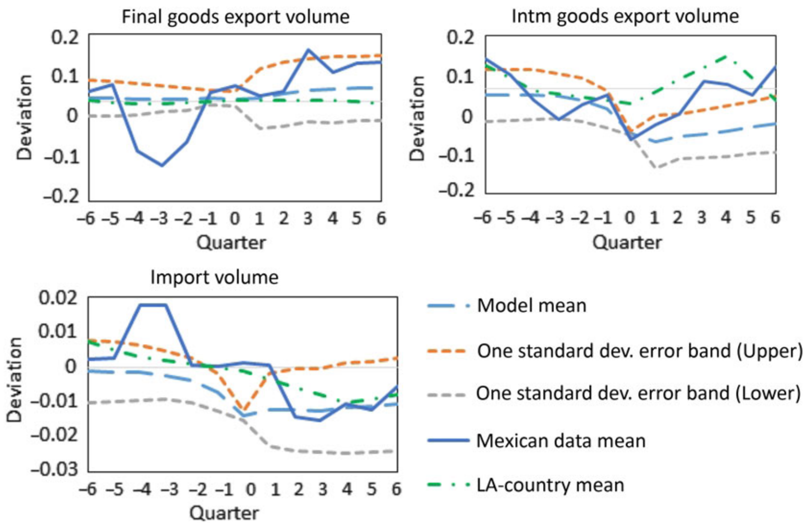

Note: All data are real, logged, and HP-filtered. Since there are no intermediate goods export volume data available for Mexico, I use the export value measured in pesos to approximate the volumes.

FIGURE 3. Trade volume of borrower country 2 around default events.

Note: All data are real, logged, and HP-filtered. The model results for export values are measured in creditor country 1's final goods 1.

FIGURE 4. Trade dynamics of borrower country 2 around default events.

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calibration, but the changes to final goods export value and total export value are not.

Figure 4 also plots the dynamics for import and total trade values. The model does well in matching the declining import value upon default, given that most of the data path is within the error band of the model result. Adding import value and export value together, total trade value declines, which is consistent with the finding of Rose (2005). Notice that trade values are denominated in country 1's goods. Hence, changes to import values are the same as those to import volumes in the model, while changes to export values are composed of those to export volumes and those to the relative price. Even though in terms of volume, imports decline more than exports do, the former decline about the same as the latter in terms of value in the model.

3.5. Comparative Analyses

In this section, I conduct comparative analyses to examine the effect of changes to important parameters and evaluate the robustness of the model's qualitative results. In particular, I re-solve the model with different values of post-default efficiency loss in the intermediate goods exports (ϵ), the share of imported intermediate goods input used in the creditor country's production (α_3), and the borrower country's consumption home bias (ρ_2). These results are summarized in Table 3.

3.5.1. Post-default efficiency loss in intermediate goods export sector. It is important to experiment with different values of ϵ because it governs the magnitude of post-default losses in the demand for the defaulting country's intermediate goods, and thus also losses in its income, terms of trade, real exchange rates, and trade flows. In Table 3, I report results using a higher $\epsilon = 0.87$ (i.e., a smaller efficiency loss in the creditor country's production operations with the defaulting country's intermediate goods) than that in the baseline $\epsilon = 0.85$. Even though the results change slightly under different values of ϵ, the signs of all the statistics remain consistent with the data.

A greater value of $\epsilon = 0.87$, that is, a smaller efficiency loss, induces two main effects. First, the borrower maintains a lower average debt-to-GDP ratio. Second, it induces a smaller decline in intermediate goods demand and a smaller loss in wage income that make the borrower's terms of trade and real exchange rates less responsive to a default crisis. Thus, the volatility of the terms of trade and the real exchange rates are lower, as are their correlations with GDP and bond spreads. It is also important to notice that when there is no efficiency loss, the standard deviations decrease further.

3.5.2. Intermediate input share. I also vary α_3 to examine the effect of changes in the intermediate input share in final goods 1's production (baseline $\alpha_3 = 0.54$). With a lower intermediate input share ($\alpha_3 = 0.52$), final goods 1's production

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TABLE 3. Comparative analyses

Statistics	Data	Baseline	$\epsilon = 0.87$	$\alpha_3 = 0.52$	$\rho_2 = 0.6$
Ave. debt/GDP ratio (%)	74.94	6.16	4.30	5.05	41.02
Ave. spreads (%)	4.35	7.92	8.26	8.25	5.69
Spreads std. dev. (%)	4.71	2.32	2.28	2.25	2.25
REXR std. dev. (%)	17.30	3.33	2.98	3.45	0.36
Terms of trade std. dev. (%)	6.21	4.53	4.11	4.58	1.99
Dom. prod. cons. std/GDP std.	1.23	1.01	1.01	1.00	1.38
Total cons. std./GDP std.	1.12	1.05	1.04	1.04	1.09
Trade balance std. (%)	2.08	1.04	0.82	0.93	1.13
Correlation with GDP					
Bond spreads	−0.39	−0.70	−0.69	−0.72	−0.35
Real exchange rate	0.53	0.39	0.26	0.39	−0.89
Terms of trade	0.25	0.40	0.27	0.38	−0.87
Trade balance/GDP	−0.65	−0.27	−0.25	−0.28	−0.43
Total exports	0.21	0.67	0.70	0.69	0.99
Intermediate goods exports	0.18	0.68	0.70	0.70	1.00
Total import	0.75	0.86	0.85	0.86	0.97
GDP volume	0.65	0.81	0.83	0.80	0.99
Default occurrence	−0.14	−0.23	−0.23	−0.23	−0.14
Correlation with bond spreads					
Real exchange rate	−0.76	−0.65	−0.60	−0.64	0.21
Terms of trade	−0.13	−0.70	−0.65	−0.69	0.15
Trade balance/GDP	0.30	0.07	0.08	0.08	−0.03
Total exports	−0.02	−0.76	−0.78	−0.79	−0.38
Intermediate goods exports	−0.08	−0.79	−0.80	−0.80	−0.38
Total import	−0.28	−0.79	−0.80	−0.80	−0.32
GDP volume	−0.19	−0.33	−0.34	−0.34	−0.31
Default occurrence	0.18	0.26	0.25	0.25	0.42

Note(s): Except for bond spreads, debt-to-GDP ratio, and default occurrence, all other data in the table are HP-filtered. All data are in real terms and at quarterly frequency.

becomes less affected by the efficiency loss in operations with intermediate inputs from the defaulting country. This reduces the impact of a sovereign default on terms of trade and real exchange rate. We can see that they become slightly less correlated to output and bond spreads, than in the baseline. Moreover, less vertical export also produces less volatility in bond spreads, total consumption, and trade balance. This result may shed light on risk sharing literature by incorporating both sovereign default risk and vertical export in a model. Additionally, less vertical export also supports a smaller debt-to-GDP ratio with a higher average spread.

3.5.3. Consumption home bias. Last, when I shut down the consumption home bias (i.e., g_1 is no longer larger than g_2) by reducing ρ_2 from 0.9 to 0.6 (country 2's home goods consumption share is reduced from 80% to 40%), the correlations of real exchange and terms of trade with GDP and bond spread are no

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longer consistent with the data, as predicted by the propositions and the model mechanism. Meanwhile, the default frequency is drastically reduced to 0.001 because a default event is very costly as a large share of the borrower country consumption is foreign. Hence, the country can borrow more than what is in the baseline.

4. EMPIRICAL ANALYSIS

Although this is not an empirical paper, this section provides some support for the sovereign-default-triggered efficiency loss to creditor-country firms' production that uses defaulting countries' intermediate goods inputs. In order to test for a decline in the output and what type of firms are affected more in the creditor country in the aftermath of other countries' sovereign default, I estimate the following reduced-form equation:

$$y_{it} = \beta_1 + \beta_2 X_t + \beta_3 LAdf_t + \beta_4 LAdf_t \times Depd_{it} + \beta_5 Depd_{it} + \varepsilon_{it}, \quad \textbf{(23)}$$

where y_{it} is a measure of the creditor country's output cycles in industry i at time t. Here I use HP-filtered log US industry output, which removes both industry-specific and nationwide trends. Hence, no industry fixed effects are needed because all industry outputs are filtered to fluctuate around zero. I also use log US industry output without being filtered as a measure of y_{it} as a robustness check, where industry fixed effects and industry-specific linear trends are added to the above specification to control for different industry output levels and trends over time. β_1 is a constant, and X_t is a set of time fixed effects accounting for nationwide business cycles. After controlling the abovementioned, I have isolated the output variations to contain only industry-specific business cycle components, which is exactly what is needed to examine the impact of borrower countries' default events through intermediate inputs. The key coefficients are β_3 and β_4 for variable $LAdf_t$ and its interaction with $depd_{it}$, respectively. $LAdf_t$ is a $0/1$ indicator of borrower countries being in default episodes at time t. $Depd_{it}$ is the creditor country industry i's dependency on the inputs from borrower countries. If both β_3 and β_4 are statistically significant and negative, it implies that sovereign defaults have more severe and more negative impacts on the output of the creditor's industries that depend more on the defaulting country's inputs. Lastly, the regression also controls for $Depd_{it}$, and ε_{it} is a set of errors.

In the empirical analysis, I use Brazil and Mexico as a group for the defaulting countries and the USA for the creditor country. The choice of Brazil and Mexico is determined by the data constraint for LA cross-country input-output tables. I collect US Industrial Production Index data on 14 manufacturing industries for the period of January 1981 to December 2012 (monthly). From world input-output tables, I calculate the share of Brazilian and Mexican inputs out of total intermediate inputs used in each of those US manufacturing industries, to measure

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TABLE 4. The impact of LA default episodes on US industry output

Key variables	(1) HP-log US output		(2) Log US output	
LA defaults	−0.0071	*	−0.0434	***
	(0.0038)		(0.0069)	
LA defaults × US depd.	−0.0008	*	−0.0050	***
	(0.0004)		(0.0010)	
Time fixed effects	*Yes*		*Yes*	
Industry fixed effects	*No*		*Yes*	
Industry trend	*No*		*Yes*	
Observations	5376		3276	
R-squared	0.543		0.927	

Note(s): In the column (1), the dependent variable is HP-filtered log US output by industry. The HP-filtering removes trends, including industry-specific trends. Hence, no industry trend variables are needed. The monthly data sample runs from January 1981 to December 2012. Column (2) presents the robustness check. The dependent variable is log US output by industry. Industry-specific linear trends and industry fixed effects are added as additional controls and the data up to December 2007 are used to avoid the Great Recession period when industry trends became strongly nonlinear. Other controls in both regressions include time fixed effects and US industry dependency on LA inputs (in %). The parentheses below coefficient estimates report standard errors. The symbols * and *** denote statistical significance at the 10% and 0.1% levels, respectively.

their dependency on LA inputs. Given data limitation, the dependency measurement is annual from 1995 to 2011. For the period before 1995, the dependency value of 1995 is used; for the periods after 2011, the value of 2011 is used. Hence, the dependency is constant during Brazilian and Mexican default episodes in the 1980s; there is no endogeneity issue from US output to the dependency. The default episodes are defined as 1982–1983, 1986–1987, and 1989–1990.

Table 4 presents the regression results. The result in the first row suggests that during Brazilian and Mexican default episodes US manufacturing output across industries decreases by 0.7–4.3%. LA sovereign defaults do have negative impacts on US output. In fact, this negative impact found here is comparable to the simulated model result on the creditor country's output loss (0.14%) in the model result section.

More importantly, the regression results in the second row suggest that for every 1 percentage point that a US industry's inputs depend on Brazilian and Mexican inputs, a 0.1–0.5% more output decline occurs in that US industry during Brazilian and Mexican default episodes. Putting the result in perspective, the average share of Brazilian and Mexican inputs out of total intermediate inputs used in US manufacturing industries over the sample period is 1%. In other words, a US industry that uses more Brazilian and Mexican inputs is more negatively affected by those LA default episodes than a US industry that uses fewer such inputs. This result supports the model setup where the default-triggered efficiency loss ϵ is

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only applied to the creditor country firms' production that uses imported inputs from the defaulting country.

5. CONCLUSION

This paper proposes a two-country model of sovereign default, including endogenous default risk, consumption home bias, and a default penalty on cross-border vertical production. It contributes to the literature by generating endogenous income, trade flows, terms of trade, and real exchange rate that interact with default risk, as well as generating their deterioration upon default.

The model features a novel terms-of-trade amplification channel that links sovereign default risk and events with trade flows and income. As a country borrows more and more, its default risk and interest rate increase, its wealth declines, world relative demand for its final goods decreases, and its terms of trade deteriorates, which in turn reduces the borrower country's income and raises its default risk. Once the borrower does default, its wealth declines further, its terms of trade and real exchange rate deteriorate sharply. The real depreciation then takes another toll on the defaulter's income and trade values.

The model results are consistent with two important stylized facts of emerging markets' business cycles and sovereign defaults. First, it delivers procyclical trade flows over business cycles. Second, this model accounts for deterioration in the terms of trade and the real exchange rate, and reductions in trade flows upon default. Moreover, the model does not need an exogenous endowment loss following a sovereign default, but endogenously generates GDP losses, partially from real depreciation, and partially from production activity reductions. This model also offers a new perspective on how vertical production (α_3), default penalty (ϵ), and consumption home bias (ρ_2) interact with default risk, thus debt levels and macroeconomic volatility.

This line of research into the connections between default risk, income, trade flows, and terms of trade is far from complete. It would be interesting to study what happens when *both* countries suffer productivity shocks. Valid questions to ask include the following: how are the shocks transmitted across countries, and how is the risk shared in a sovereign default model with international goods trade? In particular, this model with the defaulting penalty associated with vertical integration has the potential to explain why international risk sharing worsens for emerging markets after global financial integration (Bai and Zhang (2012)).

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit https://doi.org/10.1017/S1365100519000701

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NOTES

1. Rose (2005), Cuadra and Sapriza (2006), Reinhart and Rogoff (2011), and Mendoza and Yue (2012).

2. This paper considers a group of developing countries and emerging markets with correlated sovereign default risk (e.g., LA countries, or Euro zone peripheral countries) as one borrowing entity. As illustrated in the model and result sections of this paper, the model considers this group of countries acting like a small open economy in the international bond market and like a large open economy in the international goods trade market.

3. Data are from World Integrated Trade Solution (WITS) website.

4. It is worth emphasizing that, as in previous sovereign default models, this paper's default also arises in equilibrium as an optimal decision of a benevolent government.

5. Past empirical research suggests that less outward-oriented sovereigns are more willing to default. Therefore, if a sovereign government internalizes its citizens' desire for imported goods, we can begin to consider how a country's reduced desire for foreign goods can spur defaults, or how we can motivate the country to service its debt on time.

6. The relevant figure is not included in this version of the paper due to space limitation, but is available in earlier versions of this paper. All data are real, logged, and HP-filtered. Raw data sources are detailed in the Online Appendix.

7. For instance, this model can also be applied to the recent European debt crisis, with peripheral countries as the borrower and France and Germany as the creditor. Even though not all peripheral countries defaulted on their debt, their spreads all soared and they were experiencing a cross-border capital flow "sudden stop" (Baldwin and Giavazzi (2015)).

8. These include but are not limited to works by Backus et al. (1992, 1994), Mendoza (1995), Stockman and Tesar (1995), Heathcote and Perri (2002), Kehoe and Perri (2002), Kose (2002), Broda (2004), Iacoviello and Minetti (2006), Bodenstein (2008), and Raffo (2008).

9. Asonuma (2014) uses traded and non-traded goods to generate real depreciation in his model, similar to the idea proposed by Arellano and Kocherlakota (2014). The mechanism of non-traded goods works similarly to the mechanism of two countries' consumption home bias in this paper.

10. One way to interpret the creditor country's constant productivity is that it always can smooth its production through other financial channels that are not in this model, regardless of the situation in the bond market with the borrower country. Moreover, since the creditor country never defaults, it is not of interest in this paper to complicate the model results by including its productivity shocks. It would be of future research interest, however, to study the spillover effects when a creditor country's productivity shocks trigger a borrower country's sovereign default.

11. Another setup is creditor country 1's imported intermediate goods and domestic labor directly substitute each other imperfectly as inputs, and produce final goods 1 with capital. Similar results are expected, but it emphasizes the role of labor substitution in the creditor country, whereas the current setup emphasizes the role of capital allocation and has the flexibility to interpret k_m as FDI stock or capital goods imports to the borrower country.

12. Since this model is calibrated after the USA and LA countries, an asymmetric model in terms of production and factor endowment is more realistic, and its parameters are set to target their different labor shares in production and capital stocks from the data. Nevertheless, I do not think the two countries' difference in their goods' labor/capital intensities will drive the key results on trade changes in this paper. Because, as I will explain later, the key mechanism lies in the income loss caused by factor reallocation across sectors during crises and consumption home bias, it does not matter which input factor is being reallocated in each country. The asymmetry in two countries' production is assumed to be consistent with data reality.

13. More specifically, assuming one or both countries produce intermediate goods with labor or capital by a linear production function to use them for its own final goods production, the effect would be essentially the same to the model's current setup where labor and capital inputs directly go into the final goods production. That is, when the borrower defaults, the creditor country demands fewer foreign intermediate goods, and both countries have to reallocate labor or/and capital inputs among

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different sectors' productions, which causes production inefficiency because the inputs are imperfect substitutes and reduces a country's total output and income. To keep the model simple, I do not include intermediate goods for domestic purpose in the model.

14. Some may argue that it is not realistic to also exclude the creditor from the international financial market. But since the creditor country has no productivity shock in this model, its consumption losses from the bond market exclusion are reduced. Assuming the creditor country has access to financial market at all time is not essential to this paper's mechanism, in fact it can make this paper's predictions on terms of trade stronger. This is because the demand of country 1's final goods relative to country 2's will increase further.

15. The model results would not be different if country 1's firms internalize the production decision of the intermediate goods sector in borrower country 2. The arrangement would be similar to that used in the global sourcing literature (Antras and Helpman (2004)). But the current setup helps the model clarify that the default-triggered efficiency loss negatively affects the demand of the foreign input that is affected, not the supply.

16. There lacks empirical evidence in the literature that other countries impose trade sanctions on defaulting countries (Martinez and Sandleris (2011) and Tomz and Wright (2013)).

17. The qualitative results do not change if using unit value index or Paasche price index.

18. As proven in the Online Appendix, consumption home bias in both countries is a sufficient condition to reduce the world relative demand of final goods 2 when the country's world wealth share declines. The more home biased the two countries are, the more the relative demand decreases.

19. Usually high unemployment occurs during default episodes, but for my calibration of LA countries, their official unemployment rates have been relatively low in comparison with international standards, because of informal sectors.

20. In general, emerging markets' wage fluctuations are more volatile than developed countries', while their employment fluctuations are less volatile, as documented by Li (2011).

21. In equilibrium, the world relative quantity of final goods 2-to-1 declines.

22. I have also calibrated the model to Mexican data alone, the main qualitative results do not change.

23. Without default risk, θ_1 and θ_2 also determine the values for the elasticity of intertemporal substitution for both countries. But with default risk, the intertemporal elasticity decreases with the risk.

24. Here the major LA countries refer to Argentina, Brazil, Chile, Mexico, and Peru.

25. To estimate that, I calculate the bond price without default risk as $q(b, b', s) = \beta_1 \frac{E_1 \frac{\partial U}{\partial c'_{11}}}{\lambda_1}$, given the current model result b'.

26. The correlation for Argentina is 34.8%, Brazil 66.4%, Croatia 13.1%, Ecuador 5.2%, Greece 17.1%, Iceland 41.8%, Indonesia 24.4%, Moldova 26.2%, Peru 52.6%, Russia 66.1%, South Africa 56.4%, Thailand 55.5%, Turkey 7.2%, Ukraine 81.8%, Uruguay 58.5%, and Venezuela 43.3%. Using HP-filter, the average correlation is 33%.

27. For Mexico, I use quarterly data and the default quarters are 1982Q4 (from Mendoza and Yue (2012)), 1986Q3 (from the Paris Club), and 1989Q2 (from the Paris Club). For the group of LA countries, given data limitation I use annual data and approximate their quarterly estimates using moving averages for the missing quarters.

28. This section uses the same simulation results as the previous section.

REFERENCES

Aguiar, M. and G. Gopinath (2006) Defaultable debt, interest rates and the current account. *Journal of International Economics* 69, 64–83.

Aguiar, M. and G. Gopinath (2007) Emerging market business cycles: The cycle is the trend. *Journal of Political Economics* 115, 69–102.

https://doi.org/10.1017/S1365100519000701 Published online by Cambridge University Press

Aizenman, J. and N. Marion (2004) The merits of horizontal versus vertical FDI in the presence of uncertainty. *Journal of International Economics* 62, 125–148.

Alessandria, G., J. Kaboski and V. Midrigan (2010) Inventories, lumpy trade, and large devaluations. *American Economic Review* 100(5), 2304–2339.

Alessandria, G., S. Pratap and V. Yue (2014) Export Dynamics in Large Devaluations. Working Paper.

Antras, P. and E. Helpman (2004) Global sourcing. *Journal of Political Economy* 112(3), 552–580.

Arellano, C. (2008) Default risk and income fluctuations in emerging economies. *American Economic Review* 98(3), 690–712.

Arellano, C. and N. Kocherlakota (2014) Internal debt crises and sovereign defaults. *Journal of Monetary Economics* 68(S), S68–S80.

Asonuma, T. (2014) Sovereign Defaults, External Debt and Real Exchange Rate Dynamics. IMF Working Papers: No. 16/37.

Asonuma, T., M. Chamon and A. Sasahara (2016) Trade Costs of Sovereign Debt Restructurings: Does a Market-Friendly Approach Improve the Outcome?" IMF Working Papers: No. 16/222.

Backus, D., P. Kehoe and F. Kydland (1992) International real business cycles. *Journal of Political Economy* 100(4), 745–775.

Backus, D., P. Kehoe and F. Kydland (1994) Dynamics of the trade balance and the terms of trade: The J-curve? *American Economic Review* 84(1), 84–103.

Bai, Y. and J. Zhang (2012) Financial integration and international risk sharing. *Journal of International Economics* 86, 17–32.

Baldwin, R. and F. Giavazzi (2015) The Eurozone Crisis - A Consensus View of the Causes and a Few Possibile Remedies. CEPR Press, A VoxEU.org e-Book at http://www.voxeu.org/content/eurozone-crisis-consensus-view-causes-and-few-possible-solutions.

Baldwin, R. and P. Krugman (1989) Persistent trade effects of large exchange rate shocks. *Quarterly Journal of Economics* 104(4), 821–854.

Bergin, P. R. (2006) How well can the new open economy macroeconomics explain the exchange rate and current account? *Journal of International Money and Finance* 25(5), 675–701.

Bleaney, M. (2008) The terms of trade, repudiation and default on sovereign debt. *Economics Bulletin* 6(22), 1–8.

Bodenstein, M. (2008) International asset markets and real exchange rate volatility. *Review of Economic Dynamics* 11(3), 688–705.

Bowen, H. P., E. Leamer and L. Sveikauskas (1987) Multicountry, multifactor tests of the factor abundance theory. *American Economic Review* 77(5), 791–809.

Brennan, M. and H. Cao (1997) International portfolio investment flows. *Journal of Finance* 52, 1851–1880.

Broda, C. (2004) Terms of trade and exchange rate regimes in developing countries. *Journal of International Economics* 63(1), 31–58.

Broner, F., T. Didier, A. Erce and S. Schmukler (2013) Gross capital flows: Dynamics and crises. *Journal of Monetary Economics* 60, 113–133.

Bulow, J. and K. Rogoff (1989) A constant recontracting model of sovereign debt. *Journal of Political Economy* 97(1), 155–178.

Chari, V. V., P. J. Kehoe and E. R. McGrattan (2002) Can sticky price models generate volatile and persistent real exchange rates? *Review of Economic Studies* 69(3), 533–563.

Cuadra, G. and H. Sapriza (2006) Sovereign Default, Terms of Trade and Interest Rates in Emerging Markets. Banco de México, Working Papers: No. 2006-01.

Drozd, L. and J. Nosal (2012) Understanding international prices: Customers as capital. *American Economic Review* 102(1), 364–395.

Eaton, J. and M. Gersovitz (1981) Debt with potential repudiation: Theoretical and empirical analysis. *Review of Economic Studies* 48, 289–309.

Engel, C. and J. Wang (2011) International trade in durable goods: Understanding volatility, cyclicality, and elasticities. *Journal of International Economics* 83(1), 37–52.

https://doi.org/10.1017/S1365100519000701 Published online by Cambridge University Press

Feenstra, R. C., P. Luck, M. Obstfeld and K. N. Russ (2014) In Search of Armington Elasticity. NBER Working Papers: No. 20063.

Fuentes, M. and D. Saravia (2010) Sovereign defaulters: Do international capital markets punish them? *Journal of Development Economics* 91, 336–347.

Gelos, G., R. Sahay and G. Sandleris (2011) Sovereign borrowing by developing countries: What determines market Access? *Journal of International Economics* 83(2), 243–254.

Gopinath, G. and B. Neiman (2014) Trade adjustment and productivity in large crises. *American Economic Review* 104(3), 793–831.

Heathcote, J. and F. Perri (2002) Financial autarky and international business cycles. *Journal of Monetary Economics* 49(3), 601–627.

Iacoviello, M. and R. Minetti (2006) International business cycles with domestic and foreign lenders. *Journal of Monetary Economics* 53(8), 2267–2282.

Kehoe, P. and F. Perri (2002) International business cycles with endogenous incomplete markets. *Econometrica* 70(3), 907–928.

Kose, A. (2002) Explaining business cycles in small open economies: How much do world prices matter? *Journal of International Economics* 56(2), 299–327.

Krugman, P. (1980) Scale economies, product differentiation, and the pattern of trade. *American Economic Review* 70(5), 950–959.

Laeven, L. and F. Valencia (2018) Systemic Banking Crises Revisited. IMF Working Papers: No. 18/206.

Li, N. (2011) Cyclical wage movements in emerging markets compared to developed economies: The role of interest rates. *Review of Economic Dynamics* 14, 686–704.

Lizarazo, S. V. (2013) Default risk and risk averse international investors. *Journal of International Economics* 89, 317–330.

Lubker, M. (2007) Labour shares. Policy Brief, Policy Integration Department, International Labour Office (ILO).

Martinez, J. V. and G. Sandleris (2011) Is it punishment? Sovereign defaults and the decline in trade. *Journal of International Money and Finance* 30(6), 909–930.

Mendoza, E. G. (1995) The terms of trade, the real exchange rate, and economic fluctuation. *International Economic Review* 36(1), 101–137.

Mendoza, E. G. (2002) Credit, Prices and Crashes: Business Cycles with a Sudden Stop. Chapter 7 of Preventing Currency Crises in Emerging Markets, University of Chicago Press.

Mendoza, E. G. (2010) Sudden stops, financial crises and leverage. *American Economic Review* 100, 1941–1966.

Mendoza, E. G. and C. Arellano (2003) Credit frictions and 'Sudden Stops' in small open economies: An Equilibrium Business Cycle Framework for Emerging Markets Crises. Chapter 7 of Dynamic Macroeconomic Analysis: Theory and Policy in General Equilibrium, Cambridge University Press.

Mendoza, E. G. and V. Yue (2012) A general equilibrium model of sovereign default and business cycles. *Quarterly Journal of Economics* 127(2), 889–946.

Milesi-Ferretti, G. and C. Tille (2010) The great retrenchment: International capital flows during the global financial crisis. *Economic Policy* 66, 285–330.

Na, S., S. Schomitt-Grohe, M. Uribe and V. Yue (2018) The twin Ds: Optimal default and devaluation. *American Economic Review* 108(7), 1773–1819.

Ostry, J. and C. Reinhart (1992) Private saving and terms of trade shocks: Evidence from developing countries. *International Monetary Fund Staff Papers* 39(3), 495–517.

Popov, S. V. and D. G. Wiczer (2014) Equilibrium Sovereign Default with Exchange Rate Depreciation. Federal Reserve Bank of St. Louis Working Paper Series: No. 2014-049A.

Raffo, A. (2008) Net exports, consumption volatility and international business cycle models. *Journal of International Economics* 75(1), 14–29.

Reinhart, C. M. (2010) This Time is Different: Country Histories on Debt, Default, and Financial Crises. NBER Working Papers: No. 15815.

https://doi.org/10.1017/S1365100519000701 Published online by Cambridge University Press

Reinhart, C. M. and K. S. Rogoff (2011) From financial crash to debt crisis. *American Economic Review* 101(5), 1676–1706.

Richmond, C. and D. A. Dias (2009) Duration of Capital Market Exclusion: An Empirical Investigation (July 1, 2009). Available at SSRN: https://ssrn.com/abstract=1027844 or http://dx.doi.org/10.2139/ssrn.1027844.

Rose, A. K. (2005) One reason countries pay their debts: Renegotiation and international trade. *Journal of Development Economics* 77(1), 189–206.

Rose, A. K. and M. Spiegel (2004) A Gravity Model of Sovereign Lending: Trade, Default, and Credit. IMF Staff Papers, vol. 51(s1), pp. 50–63. Palgrave Macmillan.

Ruhl, J. K. (2008) The Elasticity Puzzle in International Economics. Mimeo, University of Texas at Austin.

Schott, P. K. (2003) One size fits all? Heckscher–Ohlin specialization in global production. *American Economic Review* 93(3), 686–708.

Stockman, A. and L. Tesar (1995) Tastes and technology in a two-country model of the business cycle: Explaining international co-movements. *American Economic Review* 85(1), 168–185.

Tauchen, G. and R. Hussey (1991) Quadrature-based methods for obtaining approximate solutions to nonlinear asset pricing models. *Econometrica* 59(2), 371–396.

Tille, C. and E. van Wincoop (2008) International capital flows. *Journal of International Economics* 80, 157–175.

Tomz, M. and M. Wright (2013) Empirical research on sovereign debt and default. *Annual Review of Economics, Annual Reviews* 5(1), 247–272.

United Nations Economic Commission for Latin America and the Caribbean (2013) *Foreign Direct Investment in Latin America and Caribbean*. United Nations: Santiago, Chile.

Yue, V. Z. (2010) Sovereign default and debt renegotiation. *Journal of International Economics* 80, 176–187.

Zymek, R. (2012) Sovereign default, international lending, and trade. *IMF Economic Review* 60, 365–394.

https://doi.org/10.1017/S1365100519000701 Published online by Cambridge University Press