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'Sudden Stops' in an Equilibrium Business Cycle Model with Credit Constraints: A Fisherian Deflation of Tobin's q[*]

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Recent "Sudden Stops" in emerging economies are puzzling. In a Sudden Stop, a country suffers a loss of access to world capital markets, a sharp current account reversal, and collapses in output, absorption and asset prices. Sudden Stops appear in the data as recessions larger than normal cyclical downturns, suggesting that their cause could be large, unanticipated shocks to credit market access. However, this explanation is at odds with the history of these events and it leaves the credit crunch unexplained. Why economies in which agents know that Sudden Stops can happen become vulnerable to experience these crises? Can a business cycle model that explains normal cycles account for Sudden Stops without recurring to large, unexpected shocks? This paper answers these questions using an equilibrium business cycle model in which the underlying shocks driving normal business cycles can trigger credit constraints on foreign debt and working capital financing. When these constraints bind, they cause three "credit channel" effects that magnify the effects of shocks, making recessions larger and more persistent. Two are endogenous external financing premia on foreign debt and working capital. The third is Fisher's debt-deflation mechanism. Sudden Stops emerge as the equilibrium response to typical realizations of adverse shocks when the economy is highly leveraged, and these high leverage states are reached with positive probability in the long run.

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1. Introduction

Business cycles are defined by the features of variability, co-movement and persistence observed in the deviations from trend of macroeconomic time series over time. The experience of the Great Depression showed, however, that occasionally economies suffer deep recessions that differ markedly from the recession phase of a typical business cycle downturn. These unusually deep recessions were also a central feature of the recent crises in emerging markets. In contrast with the Great Depression, in the emerging markets crises a sudden loss of access to international capital markets played a key role in triggering and propagating financial crashes and economic collapse. That is, in emerging economies we observed what Calvo (1998) labeled a "Sudden Stop."

A Sudden Stop is characterized by three striking stylized facts: First, a sharp reversal in the current account, triggered by the sudden loss of access to world credit markets. Second, a deep recession, with large declines in domestic output, consumption and investment. Third, large relative price swings, with a collapse in domestic asset prices and the price of nontradable goods relative to tradables, and a sharp increase in the relative price of intermediate goods. The deviations from trend in output, consumption and investment observed during Sudden Stops are well below the two-standard-deviation bands of the corresponding time series (see Mendoza (2002)). Moreover, there are statistically-significant non-linearities (skewness, kurtosis, and conditional volatility) in these cyclical components of the data (see Valderrama (2003)).

Sudden Stops seem to be a feature unique to emerging economies. Empirical evidence in Mendoza (1995) shows that, except for the fact that business cycle indicators for emerging economies display higher standard deviations than for industrial countries, the statistical moments commonly used to characterize co-movement and persistence of business cycles are fairly similar across the two groups of countries. Hence, the main difference in the business cycles of industrial and emerging economies is in the Sudden Stop phenomenon that the latter display.

Explaining Sudden Stops remains a challenging task. Most of the recent literature on Sudden Stops emphasizes the role of frictions in international capital markets as the ultimate culprit behind Sudden Stops. Several studies propose models that can explain sudden adjustments in production, absorption and the current account as a result of the adverse effects of global financial market imperfections on investment and consumption smoothing (see, for example, Calvo (1998), Gopinath (2003), Cook and Choi (2003), Cook and Deveraux (2003) and Paasche (2001)). However, national accounts data often reveals that, despite sharp declines in investment and employment, changes in capital and labor inputs account for a small fraction of the collapse (see Bergoeing, Kehoe, Kehoe and Soto (2002) and Section 2 of this paper). Thus, most of the "credit channel" transmission mechanisms that have been developed in the Sudden Stops literature will find it hard to explain observed Sudden Stops, even if they can explain investment collapses of the magnitude observed in the data.

The fact that variations in measured capital and labor account for a small fraction of a Sudden Stop's output collapse suggests that the fall in output could be caused by a drop in total factor productivity, TFP (i.e. a change in output that cannot be accounted for by changes in capital and labor). However, Section 2 of this paper shows that large declines in use of intermediate inputs (particularly imported intermediate inputs) and in plant capacity utilization account for an important fraction of the output collapse observed in Mexico's Sudden Stop of 1994-95. Interestingly, after adjusting for the contribution of intermediate inputs and capacity utilization, the TFP component of the output collapse is within the range that could be attributed to the standard exogenous TFP shocks used in Real-Business-Cycle theory to account for the business cycle of small open economies (see Mendoza (1995)).

The stylized facts of Sudden Stops suggest that a framework that seeks to integrate an explanation of this phenomenon into a theory of business cycles should meet three conditions: First, it needs a transmission mechanism that can produce infrequent Sudden Stops as a feature of the long-run stochastic stationary equilibrium of the economy nested within smoother, more common business cycles (without relying on unusually large, unexpected shocks to TFP). Second, in a Sudden Stop episode, typical realizations of the same underlying exogenous shocks that drive normal business cycles in non-Sudden Stop periods must trigger a sharp reversal in the current account, a deep recession, and a collapse in asset prices. Third, endogenous cuts in intermediate goods and capacity utilization (in response to the financial collapse reflected in the current account reversal and the asset price crash) need to be an important determinant of the output collapse.

The objective of this paper is to propose an equilibrium business cycle model that aims to meet these three conditions, and to explore to what extent the quantitative predictions of the model can account for the observed features of Sudden Stops. The model integrates some of the financial frictions studied in the Sudden Stops literature with elements of Real Business Cycle (RBC) theory. In particular, the model is based on the small open economy RBC setup with incomplete contingent claims markets (see Mendoza (1991)) modified to introduce demand for intermediate inputs and endogenous capacity utilization. The latter is modeled following the RBC analysis of Greenwood, Hercowitz and Huffman (1988), which is in turn based on the theoretical principles of Calvo (1975) -- with the difference that capacity utilization costs are modeled here as a variable production cost rather than as a cost reflected in faster depreciation of physical capital.

The standard small open economy RBC model, even if augmented with intermediate goods and endogenous capacity utilization, cannot produce Sudden Stops. Despite the incompleteness of asset markets, agents in this model have unrestricted access to a perfect international credit market. Thus, negative shocks to TFP, the world interest rate, or the world price of intermediate goods induce the consumption-smoothing and investment-reducing effects described in Mendoza (1991), and the net result is a slightly counter-cyclical (and relatively smooth) response of the current account.

Large shocks to TFP can be introduced into the model to trigger large output collapses driven by cuts in intermediate goods and capacity utilization, but this would still fail to explain the Sudden Stops' reversal of the current account and the collapse of consumption (since households would borrow from abroad to smooth consumption and the current account would remain slightly counter-cyclical). This could be remedied by adding large shocks to the world interest rate or the access to world capital markets, but this theory of Sudden Stops would hinge entirely on unexplained "large and unexpected" shocks. The shocks would need to be "large" because by definition they would need to induce recessions larger than the typical non-Sudden-Stop recessions induced by typical shocks, and they would need to be "unexpected" because otherwise agents would self-insure to undo their real effects. Moreover, this explanation of Sudden Stops would fail to explain why Sudden Stops affect emerging economies and not industrialized countries – except for the argument that large, unexpected exogenous shocks hit the former but not the latter.

The model proposed in this paper moves away from a theory of Sudden Stops based on large, unexpected shocks by introducing two financial frictions that deviate significantly from the frictionless credit market of the small open economy RBC model: First, foreign debt in one-period debt contracts cannot exceed the liquidation value of a fraction of the economy's capital stock offered as collateral. Second, firms' working capital financing for purchases of intermediate goods and capacity utilization costs cannot exceed a fraction of the market value of the firms' gross sales (net of wage costs) used as guarantee. These constraints can be viewed as originating in frictions affecting contracting relationships in credit markets, such as limited enforcement or informational asymmetries. The contracting relationships are not explicitly modeled here, however, because the emphasis is on studying the role that these constraints play in the business cycle transmission mechanism (as in the line of research on endogenous credit constraints motivated by the work of Kocherlakota (2000)).

The collateral constraint linking debt to the liquidation value of capital is in the form of the margin constraint studied by Aiyagari and Gertler (1999) and Mendoza and Smith (2003). This constraint shares some of the features of the classic collateral constraint proposed by Kiyotaki and Moore (1997) and to collateral constraints widely studied in the Sudden Stops literature (see, for example, Auenhaimer and Garcia Saltos (2000), Caballero and Krishnamurty (2001), and Mendoza and Smith (2003)). The constraint on working capital is a variation of the working capital constraint typical of limited participation models in which firms borrow funds payable at the end of the production period to finance some of their input costs. In the model of this paper, however, lenders require firms to secure working capital financing using the firms' sales or output (trade credits guaranteed on the value of shipments are one example).

From the perspective of the model's business cycle transmission mechanism, the key element of the above credit constraints is that they only bind if the economy's leverage ratios (the private debt-equity ratio or the ratio of working capital financing to gross output net of labor costs) are sufficiently high. If these ratios are low, adverse shocks to TFP, the world interest rate, or the price of intermediate inputs of the "standard" magnitude do not alter the economy's access to world credit markets and thus result in standard RBC-like dynamics. However, if the leverage ratios are high, the same "standard" shocks trigger the financial constraints and set in motion a dynamic process that results in a Sudden Stop.

Sudden Stop dynamics are driven by three "credit channel" mechanisms induced by the borrowing constraints that magnify and increase the persistence of the effects of real shocks on the economy. Two of them are in the form of endogenous external financing premia that arise because the effective costs of borrowing from abroad faced by households and firms increase when the collateral constraint on foreign debt and the constraint on working capital bind. The third is Fisher's classic debt-deflation mechanism. A Fisherian debt-deflation occurs when the collateral constraint linking foreign debt to the value of domestic capital binds, forcing agents to liquidate equity in order to meet "margin calls" triggered by the constraint. This fire sale of equity reduces the price of capital and hence tightens further the collateral constraint and causes a subsequent round of margin calls.

This approach to model Fisherian debt deflations is adopted from the work of Aiyagari and Gertler (1999) and Mendoza and Smith (2003). The setup of this paper differs in that it allows for endogenous capital accumulation and a dividend stream that varies with the collateral constraint. As a result, the Fisherian deflation hits the Tobin q and affects future dividends. The deflation of the Tobin q magnifies the investment collapse and the persistence of the output collapse triggered by the "impulse" of a real shock of standard size.

There is a mechanism with some of the flavor of the Fisherian deflation working also on the side of the working capital constraint because of the feedback between the working capital needs and the level of output. When this constraint binds, the reduced access to working capital results in lower levels of factor demands and reduced capacity utilization. These in turn result in a further decline in production, which tightens further the working capital constraint. Interestingly, with a constant-returns-to-scale (CRS) production function and competitive factor pricing, shocks to TFP or intermediate goods prices cannot trigger the working capital constraint. Only shocks to the *borrowing cost* of working capital can have this effect. These shocks to borrowing costs may reflect shocks to the world real interest rate or, as is common in emerging economies in which debt is generally denominated in units other than the goods produced by domestic firms (a phenomenon labeled "liability dollarization"), shocks to the relative price of the firms' output in terms of the unit in which debt is denominated.

High leverage ratios that leave the economy exposed to the risk of experiencing a Sudden Stop are a feature of the stochastic stationary competitive equilibrium of the economy. These high leverage ratios are reached with positive probability as the outcome of optimal plans for debt and capital accumulation under particular sequences of typical realizations of adverse shocks to TFP, the world interest rate or intermediate goods prices. Households self insure to mitigate the welfare effects of the sudden loss of access to credit markets, but these precautionary savings cannot completely eliminate the possibility of facing binding credit constraints in the long run because the credit constraints are endogenous to the process of capital accumulation and the Tobin-q valuation of physical capital.

The rest of the paper is organized as follows. Section 2 reviews the empirical regularities of Sudden Stops, with emphasis on Mexico's Sudden Stop of 1994-95. Section 3 describes the model economy and characterizes its competitive equilibrium. Section 4 conducts the numerical analysis. Section 5 concludes.

2. Empirical Regularities of Sudden Stops: The Mexican Case

There is a growing number of cross-country empirical studies that document the stylized facts of Sudden Stops (see, for example, Calvo and Reinhart (1999), Calvo and Izquierdo (2004), Milesi-Ferretti and Razin (2000)). This paper focuses instead on a detailed analysis of one Sudden Stop episode: the Mexican crash of 1995 following the December, 1994 devaluation. The goals are to use the Mexican data to quantify the stylized facts of the Sudden Stop, to identify and measure potentially relevant features of the business cycle transmission mechanism that was at work at that time, and to provide information for the calibration of the model that anchors the numerical simulation analysis undertaken in Section 4.

Table 1 summarizes key features of Mexico's business cycles and the Sudden Stop of 1995. The table provides standard measures of variability, co-movement and persistence of the main macroeconomic time series at the business cycle frequency (GDP, private consumption, fixed investment and the current account-GDP ratio) using the Hodrick-Prescott filter to isolate the cyclical components of the data. The table also reports business cycle facts for real equity prices and for the price of intermediate inputs that play a central role in the model proposed in the next section. In addition to standard business cycle moments, Table 1 reports measures of the magnitude of the Sudden Stop in each variable (defined as the lowest deviation from trend during the sample period, or the largest one in the case of the current account-GDP ratio and the price of intermediate goods) and the ratio of this measure of Sudden Stop to the standard deviation of the same variable. The latter is an indicator of the extent to which the movements observed during the Sudden Stop exceeded those of Mexico's "typical" business cycles.

The business cycle moments reported in Table 1 are in line with common business cycle facts (except that the standard deviation of consumption is larger than that of GDP, which is explained by the fact that consumption data includes durable goods). Investment is more volatile than GDP, all variables exhibit positive first-order autocorrelations, consumption and investment are positively correlated with GDP and the current account-GDP ratio is negatively correlated with GDP. Equity prices are very volatile and pro-cyclical. Intermediate goods prices also display a high standard deviation and they are countercyclical.

The 1995 Sudden Stop facts shown in the Table are more surprising. The magnitude of the recessions in GDP, consumption and investment, the size of the reversal in the current account, the collapse in asset prices and the surge in the price of intermediate goods are significantly larger than those observed in typical Mexican recessions. Except for the asset price collapse (which measured just below 2 standard deviations), the Sudden Stops in all of the macro aggregates listed in the Table are well above the two-standard deviation threshold. Figure 1 shows, in addition, that looking at deviations from the Hodrick-Prescott trend in annual per-capita GDP for the 81-year period 1920-2001, two recessions stand out from the rest: the Great Depression and the 1995 Sudden Stop.

Figure 2 uses Mexico quarterly data on the annualized current-account GDP ratio (without applying the H-P filter) to illustrate the magnitude of the sudden cutback in access to external financing during Sudden Stops from a time-series perspective. Mexico suffered Sudden Stops at the onset of the 1982 debt crisis and in 1995. In both instances, large current account deficits that were built up gradually in the years before the Sudden Stops were reversed into small surplus *in a single quarter*. The correction measured about 11 percentage points of GDP in 1982 and 8 percentage points of GDP in 1995. Figure 1 shows that the recession of the 1982 Sudden Stop was milder but more prolonged than the one of the 1995 Sudden Stop.

The time-series perspective on the corrections in relative prices of the 1995 Sudden Stop is illustrated in Figure 3. The plot shows a boom in real equity prices in the two years before the Sudden Stop, followed by a sudden collapse in 1995. The real price of imported intermediate goods rose by nearly 50 percent in 1995 and remained at high levels for almost two years. The relative price of final nontradable goods to tradable goods fell sharply, but in relative terms the surge in intermediate goods prices was over 2.5 times larger than the decline in the nontradables price. These relative price movements are important because of the “liability dollarization” problem identified in the Sudden Stops literature. The problem of liability dollarization emerges because the foreign debt obligations of agents in emerging markets are generally denominated in units of world tradable goods (i.e. in hard currencies) but this debt is leveraged on incomes and assets denominated in different units (nontradable goods or domestic differentiated tradable goods). Hence, a sudden drop in the relative price of nontradables or a sudden surge in the relative price of imported intermediate goods can have adverse effects on the ability of domestic agents to access world credit markets and service debts.

Taken together, the normal business cycle indicators and the Sudden Stop measures shown in Table 1 and illustrated in the plots pose the key question that this paper aims to address: Can we account for the observed Sudden Stop dynamics as an atypical class of economic fluctuations nested within more regular business cycles?

An analysis of Mexican national accounts data provides further insights into the characteristics of the output collapse. In particular, it shows that changes in capital and labor played a relatively small role in the observed fall in output relative to changes in use of intermediate inputs, capacity utilization, and TFP. This analysis is similar to the growth accounting exercise applied to Chile and Mexico by Bergoeing et al. (2002), BKKS, but modified to introduce intermediate inputs and capacity utilization.

Consider first the contribution of variations in the capital stock (k_t) , labor usage (L_t) and total factor productivity (A_t) to the 1995 output collapse derived from Mexican data and a Cobb-Douglas technology, $A_t k_t^{\beta} L_t^{\alpha}$. The first step to measure these contributions is to construct estimates of the factor income shares. Mexican national accounts indicate that average factor shares on GDP are about $\alpha = 0.35$ and $\beta = 0.65$ for the period 1988-2002, but these figures are subject of debate because of well-known problems in measurement of proprietor's income and other forms of labor income. Because of these concerns, BKKS used values of $\alpha = 0.7$ and $\beta =$ 0.3, which are more in line with international evidence. Using these factor shares, labor data from Mexico's national accounts and estimates of Mexico's capital stock from BKKS, a large fraction (0.83) of the 6.2 percent drop in GDP observed in 1995 is assigned to TFP. Even if the change in the capital stock is ignored because of measurement problems and adjustment costs, the TFP contribution to the output collapse is still large at 0.68. Moreover, using the factor shares calculated directly from the data, the TFP contributions with or without the change in *K* are even higher.

Consider next a Cobb-Douglas production function for gross output, $A_t k_t^{\beta} L_t^{\alpha} v_t^{\eta}$, where v_t are intermediate goods. The estimate of η implied by the 1988-2002 average share of intermediate goods in gross output is about 0.43. Given the GDP shares of capital and labor income from BKKS and this estimate of η, the implied factor shares of capital and labor in gross output are $\alpha = 0.4$ and $\beta = 0.17$. Combining national accounts data on labor and intermediate inputs, the BKKS capital stock estimates, and these factor shares, the contribution of TFP to the output collapse falls to 0.53. Moreover, in this gross output specification, using the factor shares of *K* and *L* obtained directly from the data instead of the BKKS estimates makes little difference for the contribution of TFP (the TFP contribution based on factor shares from the data is 0.58).

The potential contribution of changes in capacity utilization is more difficult to gauge because capacity utilization is ignored in national accounts. However, it is relatively straightforward to show that changes in capacity utilization need not be large to play an important role in the fall in output. This can be shown by rewriting the production function of gross output as $A_t(m_t kt)^{\beta} L_t^{\alpha} v_t^{\eta}$ to allow for variable capacity utilization at rate m_t. Using the factor shares from the above calculations, it is possible to calculate the residual contribution of TFP to the fall in output for a given assumed change in capacity utilization. For example, if capacity utilization fell about 9 percent in 1995, the residual contribution of TFP would fall to 0.27. If capacity utilization fell only half of that, the contribution of TFP falls to 0.4.[2]

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[2] Alternatively, survey data on capacity utilization could be used to measure *m*. However, utilization surveys in Mexico are very recent (they start in November, 1996) and cover only the manufacturing sector.

This analysis of the contributions of inputs and TFP to the fall in output indicates that if, as the bulk of the Sudden Stops literature argues, financial frictions are at the core of the transmission mechanism that trigger Sudden Stops, their effects on investment and employment are of little relevance to explain the immediate output collapse. Sudden Stops models that focus only on the investment or labor effects of financial frictions could mimic perfectly the observed falls in investment and employment and yet they would explain less than 1/5 of the fall in output. Changes in intermediate inputs and capacity utilization play a much bigger role. This suggests that models of Sudden Stops need to model gross production explicitly, and, if financial frictions are to be an issue for explaining the fall in output, they need to affect intermediate inputs and capacity utilization.

The findings of the growth accounting exercise should not be taken as suggesting that financial factors are irrelevant and shocks to TFP or factor demand are more important. The sudden and sharp reversal of Mexico's current account in 1995, from a deficit of over 5 percent of GDP to a small surplus, clearly shows that during Sudden Stops access to external financing for the economy as a whole is severely restricted. There is also evidence from firm-level data showing that (a) in the buildup phase to a Sudden Stop corporate leverage ratios rise, and (b) when the Sudden Stop hits leverage ratios collapse. Chapter II of IMF (2002) reports country and regional aggregates of leverage ratios generated with firm-level data from *Worldscope*, including ratios of debt to assets and debt to market value of equity.[3] Unfortunately, data limitations prevent computing these ratios before 1992. Still, the median debt-to-assets ratio of Mexican corporations rose by 5 percentage points in the two years before the Sudden Stop, and fell by more than 5 percentage points in the fiscal year 1995-1996. The changes in leverage are

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[3] The database *Worldscope* contains annual data on a fiscal-year basis for the main balance sheet items of all publicly-traded firms of a large list of countries, including emerging markets.

even more striking in the case of the East Asian crises. For the aggregate of emerging markets in Asia, the ratio of debt to market value of equity rose from 0.4 to 1.2 between 1996 and 1998, and then fell by 20 percentage points in the fiscal year 1998-1999.

3. A Business Cycle Model of a Small Open Economy with Financial Frictions

The model economy is a variation of the standard small open economy RBC model with incomplete insurance markets and capital adjustment costs proposed by Mendoza (1991). Two important modifications are introduced here. First, the supply-side of the model is modified to introduce demand for intermediate goods and endogenous capacity utilization. Second, the assumption of perfect credit markets is relaxed to introduce credit constraints affecting firms and households. Households face a constraint that limits their access to external debt to the market value of the fraction of their physical capital that they offer as collateral. Firms face a constraint that limits their access to working capital financing to a fraction of their gross sales net of labor costs (assuming that working capital loans are effectively guaranteed with the firms' sales).

Households

The small open economy is inhabited by a large set of identical, infinitely lived households. The preferences of the representative household are defined over stochastic sequences of consumption c_t and labor supply L_t, for $t=0,\dots,\infty$. As in Mendoza (1991), the utility function is modified to introduce an endogenous rate of time preference so as to ensure that the small open economy attains a unique, invariant limiting distribution of foreign assets.[4] Epstein (1983) shows that this requires weaker axioms on the preference order over stochastic allocations of goods than those that support the standard expected utility function with a constant rate of time preference. The standard setup requires preferences over future allocations to be

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[4] Since by definition the return on foreign assets is exogenous to the small open economy and since agents in this economy face non-insurable income uncertainty, the long-run distribution of foreign assets is not well defined with the conventional assumption of a constant rate of time preference equal to the real interest rate.

risk-independent from past allocations and past allocations to be risk-independent from future allocations, while preferences with endogenous time preference only require the latter. Epstein proved that a preference order consistent with these axioms has a von Neumann-Morgenstern representation if and only if it takes the form of the Stationary Cardinal Utility (SCU) function:

$$E_0\left[\sum_{t=0}^{\infty}\exp\left\{-\sum_{\tau=0}^{t-1}\rho\left(c_\tau - N(L_\tau)\right)\right\}u\left(c_t - N(L_t)\right)\right] \tag{1}$$

In the above expression, *u(.)* is a standard twice-continuously-differentiable and concave period utility function and *ρ(.)* is an increasing, concave and twice-continuously-differentiable time preference function. Following Greenwood et al. (1988), both functions are defined in the domain of the excess of consumption relative to the disutility of labor, with the latter given by the twice-continuously-differentiable, convex function *N(.)*. This assumption eliminates the wealth effect on labor supply by making the marginal rate of substitution between consumption and labor independent of consumption. SCU also imposes restrictions linking the *u(.)* and *ρ(.)* functions that effectively set an upper bound on the elasticity of the rate of time preference with respect to *c-N(L)*. These restrictions ensure that c_t is a normal good for all t and that the model supports a well-defined unique, invariant limiting distribution (see Epstein (1983)).

There are other methods that yield well-defined stochastic stationary equilibria in models of the small open economy. These methods include setting a fixed rate of time preference arbitrarily higher than the interest rate, modeling households with stochastically finite lives, or introducing ad-hoc changes to make the world interest rate depend on foreign assets or to pay long-run costs in trading these assets (see Arellano and Mendoza (2003) and Schmitt-Grohe and Uribe (2002)). The method using the SCU utility function has the advantage that it is consistent with two standard features of RBC models: agents are infinitely-lived and the rate of time preference and the rate of interest are equalized in the long run. Moreover, this method is in line with the aim to model economic behavior from first principles, rather than imposing exogenous functional forms linking foreign assets to their prices.

In the context of models with financial frictions like the one developed here, preferences with endogenous discounting have the extra advantage that they support stationary equilibria with binding credit constraints. This is because a binding credit constraint drives a wedge between the intertemporal marginal rate of substitution in consumption and the rate of interest. In a stationary state with a binding credit constraint, the rate of time preference adjusts endogenously to accommodate this wedge. In contrast, in models with an exogenous discount factor credit constraints never bind in the long run (if the rate of time preference is set greater or equal than the world interest rate) or always bind at steady state (if the rate of time preference is fixed below the interest rate).

Households choose sequences of consumption, labor supply, investment in domestic capital, k_{t+1}, and foreign borrowing or lending in one-period international bonds, b_{t+1}, so as to maximize SCU subject to the following period budget constraint:

$$c_t = \left(d_t + q_t(1-\delta)\right)k_t - q_t k_{t+1} + w_t L_t - b_{t+1} + b_t R \exp(\varepsilon_t^R) \qquad (2)$$

Domestic capital depreciates at a constant rate δ. Households take as given the dividend rate on capital holdings, d_t, the market price of capital, q_t, the wage rate, w_t, and the stochastic gross world real interest rate on foreign assets, $R\exp(\varepsilon_t^R)$. ε_t^R is a shock to the interest rate that follows a Markov process joint with the other exogenous shocks to be defined later in this section.

The world credit market is imperfect. In particular, lenders are assumed to require households in the small open economy to guarantee their debt by offering physical capital as collateral. The collateral constraint takes the form of the margin requirement examined in the equilibrium asset pricing models of Aiyagari and Gertler (1999) and Mendoza and Smith (2003):

$$b_{t+1} \geq -\kappa q_t k_{t+1} \tag{3}$$

Thus, households can borrow up to a fraction κ of the market value of their capital investments. This collateral constraint is not derived here from an optimal contract between borrowers and lenders. Instead, the constraint is imposed directly as in the models with endogenous credit constraints examined in the literature on credit and business cycles by Kiyotaki and Moore (1997) and Kocherlakota (2000). Still, an intuition for a credit relationship that could result in a constraint like (3) could be, for example, that limited enforcement prevents foreign lenders to collect more than a fraction κ of the value of capital holdings from defaulting debtors. In states of nature in which (3) binds, the model will produce an endogenous, market-determined premium over the world interest rate at which lenders and borrowers agree to a contract in which b_{t+1} satisfies (3).[5]

Firms

Firms in the small open economy are owned by households and hence discount future profits taking as given the representative agents' stochastic discount factors (i.e., the intertemporal marginal rates of substitution in consumption, the reciprocal of which are denoted by $\tilde{R}^{t}_{t+1}$, for t=0,…,∞ with $\tilde{R}^{-1}_{0} = 1$). Firms operate a linearly-homogeneous production function and make plans for factor demands and physical investment knowing that TFP is subject to random shocks exp(ε^A_t). They need working capital financing to pay for a fraction ϕ of their purchases of intermediate goods and direct costs of capacity utilization in advance of sales, and they incur unitary investment-adjustment costs determined by the function $\Psi(i_t/k_t)$ that is assumed to be linearly homogeneous in i_t and k_t. Intermediate goods are tradable in world

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[5] Arellano (2004), Perri and Neumeyer (2001) and Uribe and Yue (2003) present quantitative studies that examine the implications of country risk on business cycles of small open economies. Arellano's model endogenizes country risk in a setup of strategic default similar to the classic model of Eaton and Gersovitz (1981). Perri and Neumeyer and Uribe and Yue study the business cycle effects of introducing exogenous risk premia of the magnitude observed in the data into small open economy RBC models.

markets at an exogenous, stochastic relative price $p\exp(\varepsilon_t^P)$, where $\exp(\varepsilon_t^P)$ are exogenous price shocks. Capacity utilization entails a direct unitary cost determined by the continuously-differentiable, increasing function *h(.)*.[6] The credit market requires firms to guarantee their working capital debt with the value of their sales net of labor costs, so working capital financing cannot exceed the fraction κ^f of the value of sales net of wages.

The firms' problem is to choose labor demand, investment, demand for intermediate inputs, and the rate of utilization of the capital stock so as to maximize the value of the firm:

$$E_0\left[\sum_{t=0}^{\infty}\left(\prod_{j=0}^{t}\left(\tilde{R}_j^{j-1}\right)^{-1}\right)\left(\exp(\varepsilon_t^A)F(m_tk_t,L_t,v_t)-w_tL_t-\left(1+\phi r_t\right)\left(p\exp(\varepsilon_t^P)v_t+h(m_t)k_t\right)-i_t\left[1+\Psi\left(\frac{i_t}{k_t}\right)\right]\right)\right],\quad(4)$$

where $r_t \equiv R\exp(\varepsilon_t^R)-1$ is the net real interest rate, subject to the law of motion of capital,

$$i_t = k_{t+1} - k_t\left(1-\delta\right) \quad (5)$$

and the credit constraint on working capital,

$$R\exp(\varepsilon_t^R)\phi\left(p\exp(\varepsilon_t^P)v_t + h(m_t)k_t\right) \leq \kappa^f\left(\exp(\varepsilon_t^A)F(m_tk_t,L_t,v_t) - w_tL_t\right) \quad (6)$$

Working capital is a within-period loan paid off after goods at sold at the end of each period. Hence, lenders set this constraint considering the interest and principal of working capital loans, and they do not want to lend more than the discounted value of the fraction of sales net of wage costs used to guarantee the loans. The margin constraint faced by households differs because it applies to a one-period loan paid off one period after it is contracted, and the constraint calls for collateral to be put up at the time the debt contract is entered (as with typical margin loans, see Aiyagari and Gertler (1999) and Mendoza and Smith (2003) for details). Thus, the margin constraint restricts debt not to surpass the current market value of the fraction of the

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[6] This deviates from the standard capacity utilization setup in which the cost of a higher utilization rate is faster depreciation of physical capital (see Calvo (1975)). This assumption is in line with the view that *m* can be treated as an intermediate input with a cost internal to the firm. This direct cost is easier to blend in with the firms' problem while preserving Hayashi's (1982) results regarding capital adjustment costs and the marginal and average Tobin Q.

households' assets surrendered to lenders as collateral. Alternatively, the collateral constraint could be set in terms of the expected one-period-ahead discounted liquidation value of collateral assets, as in Kiyotaki and Moore (1997). However, as Mendoza and Smith (2003) showed, the time-recursive structure of the margin constraint is significantly more tractable and yet the qualitative effects of the two constraints on investment and asset prices are similar.

The Competitive Equilibrium & The Credit Channel Effects of The Financial Constraints

A competitive equilibrium for the small open economy is defined by stochastic sequences of allocations $\left[c_t, L_t, k_{t+1}, b_{t+1}, m_t, v_t, i_t\right]_0^\infty$ and prices $\left[q_t, d_t, w_t, \tilde{R}_{t+1}\right]_0^\infty$ such that:

1. Households maximize SCU subject to (2) and (3), taking as given the dividend rate, the wage rate, the world interest rate, the price of equity and the initial conditions (k_0,b_0).
2. Firms maximize the value of the firm subject to (5) and (6), taking as given the wage rate, the price of intermediate goods, the world interest rate, the household discount factors and the initial condition k_o.
3. The capital, labor and goods markets clear.

In the absence of the credit constraints, this competitive equilibrium is the same examined in standard RBC models of the small open economy. The credit constraints introduce distortions in the form of three credit-channel effects. Two of them are external financing premia affecting the cost of borrowing for households and firms and the third is the Fisherian debt-deflation process. These credit-channel effects can be analyzed by studying some of the optimality conditions of the competitive equilibrium.

The household's optimality conditions yield the following Euler equation for the optimal choice of b_{t+1}:

$$0 < 1 - \frac{\mu_t}{\lambda_t} = E_t\left[\frac{\lambda_{t+1}}{\lambda_t} R\exp(\varepsilon^R_{t+1})\right] \leq 1 \tag{7}$$

where λ_t is the non-negative Lagrange multiplier on the date-t budget constraint (2), which equals also the lifetime marginal utility of c_t or the marginal utility of wealth, and μ_t is the non-negative Lagrange multiplier on the collateral constraint (3). It follows from (7) that, when the collateral constraint binds, households face an endogenous external financing premium in the effective real interest rate at which they borrow (R^h_{t+1}) relative to the world interest rate. The expected premium is given by:

$$E_t\left[R^h_{t+1} - R\exp(\varepsilon^R_{t+1})\right] = \frac{\mu_t + \operatorname{cov}(\lambda_{t+1}, \varepsilon^R_{t+1})}{E_t\left[\lambda_{t+1}\right]}, \quad R^h_{t+1} \equiv \frac{\lambda_t}{E_t\left[\lambda_{t+1}\right]} \tag{8}$$

In the canonical small open economy RBC model, international bonds are a risk-free asset and μ_t=0 for all t, so there is no premium. If the world interest rate is stochastic, the premium can be positive or negative depending on the sign of the covariance term in (8). If the covariance is positive (negative), foreign assets are a good (bad) hedge to help smooth consumption, and hence the premium would be positive (negative). If the collateral constraint binds, there is a direct effect by which the multiplier μ_t increases the external financing premium. In addition, there is an indirect effect that is very likely to push in the same direction because a binding credit constraint makes it harder to smooth consumption, and hence the covariance between marginal utility and the exogenous world interest rate is likely to increase. When these effects are at work, the external financing premium can be viewed as the interest rate at which risk-neutral foreign lenders and domestic households interacting in a competitive credit market agree on debt contracts for loan amounts that satisfy the collateral constraint with equality.

The effects of the external financing premium on the equity price valuation of domestic households can be derived from the Euler equation for equity holdings. Solving forward this equation yields the following expression for the households' valuation of equity:

$$(1-\delta)q_t = E_t\left[\sum_{j=0}^{\infty}\left(\prod_{i=0}^{j}\left(\frac{(1-\delta)}{\tilde{R}_{t+i+1}^{t+i}}\right)\right)d_{t+1+j}\right], \quad \tilde{R}_{t+i+1}^{t+i} \equiv \frac{\lambda_{t+i}-\kappa\mu_{t+i}}{\lambda_{t+i+1}} \tag{9}$$

where $\tilde{R}_{t+i+1}^{t+i}$ is the reciprocal of the households' stochastic discount factor. Given the financing premium in (8), it can be shown that a collateral constraint binding at *t* or expected to bind at any future date, increases the rate at which future dividends are discounted and thus lowers the price of equity. In particular, the Euler equations for bonds and equity yield the following expression for the equity premium (the excess return on equity, $R_{t+1}^{q} \equiv \left(q_{t+1}+d_{t+1}\right)/q_t$, relative to the gross world interest rate):

$$\begin{aligned} E_t\left[R_{t+1}^{q}-R\exp(\varepsilon_{t+1}^{R})\right] &= \frac{\mu_t(1-\kappa)+COV_t(\lambda_{t+1},\varepsilon_{t+1}^{R})-COV_t(\lambda_{t+1},R_{t+1}^{q})}{E_t[\lambda_{t+1}]} \\ &= E_t\left[R_{t+1}^{h}-R\exp(\varepsilon_{t+1}^{R})\right]-\frac{\mu_t\kappa+COV_t(\lambda_{t+1},R_{t+1}^{q})}{E_t[\lambda_{t+1}]} \end{aligned} \tag{10}$$

This expression collapses to the standard equity premium result from asset pricing theory if the collateral constraint does not bind and the world interest rate is deterministic.

As Mendoza and Smith (2003) showed, when the collateral constraint binds it induces direct and indirect effects on the equity premium similar to those affecting the external financing premium. In fact, the equity premium increases one-to-one with the financing premium. The direct effect of the binding collateral constraint is reduced by the term $\frac{\kappa\mu_t}{E_t\left[\lambda_{t+1}\right]}$, which measures the marginal benefit of being able to borrow more by holding an additional unit of capital. Clearly, $1-\kappa$ is a positive fraction, so despite this benefit the direct effect still increases the equity premium. There is also a new element in the indirect effect that is not present in the external financing premium and is implicit in the covariance of λ_{t+1} and R^q_{t+1}: since a binding collateral constraint makes it harder to smooth consumption and self-insure, this covariance term is likely to become more negative when the constraint binds, thereby increasing the equity premium.

Given the sequence of expected equity returns from (10), the forward solution for the households' valuation of equity can be re-written as:

$$q_t(1-\delta) = E_t\left(\sum_{j=0}^{\infty}\left[\prod_{i=0}^{j}\left(\frac{(1-\delta)}{E_t\left[R^q_{t+1+i}\right]}\right)\right]d_{t+1+i}\right) \tag{11}$$

It follows then from (10) and (11) that the higher expected returns when the collateral constraint binds increase the discount rate of future dividends and lower equity prices. This occurs whenever the constraint binds at t or is expected to bind at any future date.

The above results reflect the optimality conditions that characterize the borrowing and investment choices of the household. In general equilibrium, the equity market of the small open economy clears and hence equity prices adjust so that the investment plans of households are consistent with those formulated by firms. On the side of firms, the optimality conditions for k_{t+1} and i_t produce familiar results:

$$\left(1+\Psi\left(\frac{i_t}{k_t}\right)+\left[\frac{i_t}{k_t}\right]\Psi'\left(\frac{i_t}{k_t}\right)\right)=\eta_t \tag{12}$$

$$\begin{gathered} E_t\left[\left(\tilde{R}^t_{t+1}\right)^{-1}(d_{t+1}+(1-\delta)\eta_{t+1})\right]=\eta_t \\ d_{t+1} \equiv \exp(\varepsilon^A_{t+1})m_{t+1}F_1(m_{t+1}k_{t+1},L_{t+1},v_{t+1})-h(m_{t+1})\left(1+\phi\left(r_{t+1}+\chi_{t+1}R\exp(\varepsilon^R_{t+1})\right)\right)+\left[\frac{i_{t+1}}{k_{t+1}}\right]^2\Psi'\left(\frac{i_{t+1}}{k_{t+1}}\right) \end{gathered} \tag{13}$$

where η and χ are the Lagrange multipliers on the investment equation (5) and the working capital constraint (6) respectively.

Notice from (13) that since firms discount at the households' stochastic discount factors, equilibrium in the equity market requires $\eta_t = q_t$. When this occurs, the valuations of equity made by households and firms coincide (i.e., the forward solution of (13) is the same as that obtained in (9)). Equilibrium also requires that at this market-clearing price, and the equilibrium dividend and wage rates, the resource constraint of the small open economy holds. Since the production function and the investment-adjustment cost function satisfy the conditions from Hayashi (1982), the model's marginal Tobin q, η_t equals the average Tobin q, q_t, and the resource constraint simplifies to:

$$c_t = \exp(\varepsilon_t^A) F\left(m_t k_t, L_t, v_t\right) - \left(1+\phi r_t\right)\left(p \exp(\varepsilon_t^P) v_t + h(m_t) k_t\right) - i_t \left(1 + \Psi\left(\frac{i_t}{k_t}\right)\right) - b_{t+1} + b_t R \exp(\varepsilon_t^R) \quad (14)$$

The solution for i_{t+1} given k_t and q_t implicit in the optimal investment condition of the firm in (12) can be interpreted as the firms' demand for investment resources (i.e., its equity supply function). Since (12) is a standard Tobin's q relationship, the fact that $\Psi(.)$ is increasing and convex implies that there is a positive relationship between investment demand and the equity price, or that the firms' equity supply function is upward sloping. This is because the investment adjustment cost prevents the firm from instantaneously adjusting the stock of capital to its long-run desired level.[7] Hence, when a margin call causes a negative shock to the households' demand for equity, firms can only reduce gradually the capital stock and the fall in equity demand is therefore accommodated partly with a reduction in firm investment and partly with a fall in the price of equity.

The second external financing premium triggered by the model's credit constraints is induced by the constraint linking working capital to the value of sales net of wage costs. Once

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[7] With the widely used functional form $\Psi(i/k) = (a/2)\left[(i/k) - \delta\right]$, the elasticity of investment with respect to the q is given by $(kq)/(ai)$ so in the absence of adjustment costs investment demand is infinitely elastic.

firms observe the date-t realization of the exogenous shocks, and since the date-t capital stock is predetermined at date t, firms set optimal factor demands and capacity utilization according to these marginal productivity rules:

$$\exp(\varepsilon_t^A)F_2(m_t k_t, L_t, v_t) = w_t \tag{15}$$

$$\exp(\varepsilon_t^A)F_1(m_t k_t, L_t, v_t)\left[1+\kappa^f \chi_t\right] = h'(m_t)\left[1+\phi(r_t+\chi_t R\exp(\varepsilon_t^R))\right] \tag{16}$$

$$\exp(\varepsilon_t^A)F_3(m_t k_t, L_t, v_t)\left[1+\kappa^f \chi_t\right] = p\exp(\varepsilon_t^P)\left[1+\phi(r_t+\chi_t R\exp(\varepsilon_t^R))\right] \tag{17}$$

The labor demand condition in (15) is standard. Labor demand has neutral effects on the working capital constraint because wage costs are not paid in advance and the constraint is set in terms of gross sales net of wage costs. In contrast, the conditions setting intermediate goods demand and utilization include the distortions caused by the working capital constraint. The terms in square brackets in the left-hand-side of (16) and (17) show the increase in the effective marginal product of v_t and m_t resulting from the effect the extra sales they generate have on relaxing the constraint by the amount $\kappa\chi_t$. The term $\chi_t\, Rexp(\varepsilon_t^R)$ in the right-hand-side is the firms' external financing premium that reflects the increase in the effective financing cost of working capital when the constraint binds. As with households, risk-neutral foreign lenders and firms interacting in a competitive market of working capital loans will agree to contracts with loan amounts equal to the right-hand-side of (6) at a net interest rate equal to $r_t+\chi_t Rexp(\varepsilon_t^R)$.

It is important to note that, with a constant-returns-to-scale production function, the ratio of output net of wage costs to costs of intermediate inputs and capacity utilization is independent of productivity and price shocks, and is also independent of the levels of factor utilization. Hence, in this environment the working capital constraint can only be triggered by sufficiently large interest rate shocks and, for a given interest rate shock, the constraint is equally tight for all levels of k_t, m_t, v_t and L_t.

The Fisherian deflation effect is harder to illustrate than the external financing premia because the model lacks closed-form solutions for equilibrium equity prices and investment allocations. However, the mechanism that triggers this effect can be described intuitively. When the households' collateral constraint binds, they respond to "margin calls" they get from lenders by rushing to fire-sale equity in order to satisfy the constraint. However, as explained earlier, when they do this they meet with firms that discount dividends at the same stochastic discount factors as they do and that feature an upward-sloping supply of equity because of Tobin q-adjustment costs considerations. These firms will thus find it optimal to lower investment given the reduced demand for equity and higher discounting of future dividends, and hence at equilibrium equity prices fall. But if the collateral constraint was binding at the initial equity prices and equity holdings, it must be more binding with the reduced prices and investment levels, so another round of margin calls takes place and Fisher's debt-deflation mechanism is set in motion.

4. Quantitative Analysis

This section studies the quantitative implications of the model by analyzing the results of numerical simulations of the competitive equilibrium for a version of the model calibrated to Mexican data. The main goals of this quantitative investigation are to show whether the model economy can support Sudden Stops nested within regular business cycles with both driven by the same underlying exogenous shocks, and whether these Sudden Stops can mimic the basic stylized facts of the Sudden Stops observed in the data.

Functional Forms and Numerical Solution Method

The functional forms of preferences and technology are specified as follows:

$$u(c_t - N(L_t)) = \frac{\left[c_t - \frac{L_t^{\omega}}{\omega}\right]^{1-\sigma} - 1}{1-\sigma}, \quad \sigma, \omega > 1, \tag{18}$$

$$v(c_t - N(L_t)) = \gamma\left[Ln\left(1 + c_t - \frac{L_t^{\omega}}{\omega}\right)\right], \quad 0 < \gamma \leq \sigma, \tag{19}$$

$$F\left(m_t k_t, L_t, v_t\right) = A\left(m_t k_t\right)^{\beta} L_t^{\alpha} v_t^{\eta}, \quad 0 \leq \alpha, \beta, \eta \leq 1, \ \ \alpha + \beta + \eta = 1, \ \ A > 0, \tag{20}$$

$$\Psi\left(\frac{i_t}{k_t}\right) = \frac{a}{2}\left(\frac{i_t}{k_t} - \delta\right), \quad a, \delta \geq 0 \tag{21}$$

$$h(m_t) = \frac{m_t^{\theta}}{\theta}, \quad \theta \geq 1. \tag{22}$$

The period utility and time preference functions are standard for small open economy RBC models. The parameter σ is the coefficient of relative risk aversion, ω determines the wage elasticity of labor supply, which is given by $1/(\omega-1)$, and γ is the semi-elasticity of the rate of time preference with respect to composite good $c\text{-}N(L)$. The parameter restriction $\gamma \leq \sigma$ is one of the conditions required to ensure that the SCU function can support a unique, invariant limiting distribution of the model's state variables (see Epstein (1983)).

The Cobb-Douglas production function is also standard from RBC analysis and it is the same one used in Section 2 to calculate the contribution of TFP to Mexico's 1995 output collapse. Following Hayashi (1982), the production function and the investment-adjustment cost function are linearly-homogeneous in their arguments in order to obtain a competitive equilibrium in which the marginal Tobin q, reflected in the multiplier on the investment constraint of the firms' problem, matches the average Tobin q, reflected in the asset price of the households' budget constraint. In the adjustment cost function, the parameter *a* determines the marginal adjustment cost relative to the investment-capital ratio, and the depreciation rate is subtracted from the investment-capital ratio so as to ensure that the steady-state adjustment cost is zero. Moreover, it follows from the total differential of the firms' investment optimality condition in (12) that the elasticity of investment with respect to the price of equity is given by $q_t/a(i_t/k_t)$. The isoelastic capacity utilization cost in (22) is standard from the capacity utilization literature, with the caveat mentioned before that this cost is modeled here as a direct production cost rather than as an indirect cost resulting from faster depreciation of the capital stock.

The model is solved numerically by representing the competitive equilibrium in recursive form. The recursive equilibrium can be solved by solving separately the problems of households and firms and iterating to convergence on a conjectured pricing function using the algorithm developed by Mendoza and Smith (2003) -- Arellano and Mendoza (2003) describe how to apply this algorithm to a Tobin Q model. This procedure has the disadvantage that convergence to the equilibrium pricing function with small errors can be slow and difficult to attain because the iterations do not follow a contraction mapping. Alternatively, the model can be solved by formulating a quasi social planner's problem and solving the corresponding single Bellman equation by value function iteration on a discrete state space of values for the endogenous states (k,b) and the exogenous states $(\varepsilon^A, \varepsilon^R, \varepsilon^P)$. The Bellman equation is the following:

$$V(k,b,x) = \max_{k',b',c,L,m,v} \left\{ \frac{\left(c - \frac{L^{\omega}}{\omega}\right)^{1-\sigma}}{1-\sigma} + \exp\left(-\gamma\left[Ln\left(1 + c - \frac{L^{\omega}}{\omega}\right)\right]\right) E\left[V(k',b',x')\right] \right\}$$

s.t.

$$c = \exp(\varepsilon^A) A(mk)^{\beta} L^{\alpha} v^{\eta} - i\left(1 + \frac{a}{2}\left(\frac{i}{k} - \delta\right)\right) - \left(1 + \phi(R\exp(\varepsilon^R) - 1)\right)\left(\frac{m^{\theta}}{\theta}k + p\exp(\varepsilon^P)v\right) - b' + bR\exp(\varepsilon^R) \quad (23)$$

$$b' \geq -\kappa q k'$$

$$\phi\left(\frac{m^{\theta}}{\theta}k + p\exp(\varepsilon^P)v\right) \leq \frac{\kappa^f\left[\exp(\varepsilon^A)A(mk)^{\beta} L^{\alpha} v^{\eta} - wL\right]}{R\exp(\varepsilon^R)}$$

where $x \equiv [\varepsilon^A, \varepsilon^R, \varepsilon^P]$ is the vector of current realizations of the exogenous shocks.

If the credit constraints do not bind, the Bellman equation (23) reduces to the standard social planner's *exact* representation of the competitive equilibrium of RBC models of the small open economy. The credit constraints introduce terms that include the price of equity and the wage rate, which are displaced from the planning problem using the firm's shadow price of investment (eq. (12)) and the marginal disutility of labor. This introduces distortions into the social planner's optimality condition for k' when the constraints bind because the planner takes into account how the wage rate and the equity price respond to k', and how these changes alter the ability to access the markets for external debt and working capital. The wage distortion reduces the return on investment by a term proportional to the product $(\omega-1)\kappa^f \frac{\chi'}{\lambda'} w'$ and the equity price distortion has an ambiguous sign and is given by $\frac{\kappa a}{\lambda'}\left(\mu \frac{k'}{k} - \mu' \left(\frac{k''}{k}\right)^2\right)$. Hence, these distortions are negligible if the multipliers on the constraints are small relative to the marginal utility of wealth, which are conditions verifiable in the quantitative experiments. The magnitude of "error" in computing the competitive equilibrium in this way is small compared to the average and maximum residual errors of the pricing function obtained using the Mendoza-Smith algorithm.[8]

Calibration to Mexican Data

The calibration exercise aims to match long-run empirical regularities of Mexican data with properties of the model's deterministic stationary equilibrium. The Mexican data are taken

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[8] Alternatively, the quasi social planner's problem can be viewed as representing the competitive equilibrium of an economy in which firms face a state-contingent investment tax or subsidy equal to the sum of the two distortions when the constraints bind (with the revenues rebated to households in lump-sum fashion). In this interpretation, the planner's problem matches the competitive equilibrium of the tax-distorted economy exactly.

from the same set of 1988-2001 national accounts data used in Section 2. In the deterministic stationary state, the shocks to productivity, intermediate goods prices and the world interest rate are set at their mean levels. The mean productivity and price shocks are equal to 1. The mean annual gross real interest rate is set at 1.065, which is the standard value of the real interest rate in the closed-economy RBC literature. The calibration also assumes that the values of the margin coefficient κ and the working capital constraint κ^f are low enough so that the two constraints are not binding at the deterministic stationary state.

The 1988-2001 average ratio of the cost of intermediate inputs in gross output is 0.43. Assuming that the fraction of intermediate inputs and utilization costs financed by working capital is 30 percent (i.e., $\phi=0.3$), the firms' optimality condition for demand of intermediate inputs (equation (17)) implies $\eta=0.43(1+\phi(R-1))=0.439$. This factor share, combined with the labor and capital shares on GDP from Bergoeing et al. (2002) (which are 0.7 and 0.3 respectively), implies the following factor shares in the production function of gross output: $\alpha = 0.7\left(1-\frac{\eta}{1+\phi(R-1)}\right) = 0.398$ and $\beta=1-\alpha-\eta=0.162$. The values of η, ϕ and R also imply that the ratio of gross output to GDP is $(1+\phi(R-1))/[(1+\phi(R-1))-\eta]=1.757$. Given this ratio, and assuming that the cost of capacity utilization is 3 percent of GDP, the optimality condition for capacity utilization (eq. (16)) implies that $\theta=\beta(1.757)/0.03=9.508$.

The Euler equation for capital accumulation (eq. (13)) evaluated at steady state yields an equation that determines the depreciation rate as a function of the investment-GDP ratio, the ratio of gross output to GDP and the values of β, θ, a, and R. The values of β, θ, R and the gross output-GDP ratio were determined above, and the average share of fixed investment in GDP in the data is about 16 percent. The missing parameter, a, will be set later in the stochastic simulations to match the business cycle variability of investment. However, this parameter has only a second order effect on the steady state investment Euler equation because at steady state the adjustment cost is zero, although the derivative is positive and equal to $a/2$. Setting $a=0$, the Euler equation implies $\delta=0.109$. Matching the cyclical variability of investment will require setting $a=0.375$, and with this the investment Euler equation yields $\delta=0.111$.

Demand for GDP in the data breaks down into private consumption, investment, government expenditures, and net exports. Hence, for the deterministic steady state calibration to match the average share of private consumption to GDP in the data (0.67), it needs to make an adjustment to consider government purchases. This is done by setting the deterministic steady state to match the average ratio of government purchases to GDP in the Mexican data, 0.10, assuming that these government purchases are unproductive and paid for out of a time-invariant, ad-valorem consumption tax. The tax rate is just the ratio of the GDP shares of government purchases and private consumption, 0.10/0.67=0.15, which is very close to the statutory value-added tax rate in Mexico. Since the tax is time invariant, it does not distort the households' intertemporal decision margins and its distortion on the consumption-leisure margin does not vary over the business cycle.

The households' optimality condition for labor supply equates the marginal disutility of labor with the real wage, which at equilibrium is equal to the marginal product of labor. Given the functions in (18) and (20), this equilibrium condition simplifies to: $L_t^{\omega} = \alpha \exp(\varepsilon_t^A) F(\cdot)$. Using the logarithm of this expression and Mexican data on gross output and employment growth, the implied value of the exponent parameter of labor supply in utility is $\omega=2.12$.

Given the preference and technology parameters set in the previous paragraphs, the equilibrium conditions for factor demands for m, L and v, the firms' steady-state Euler equation for capital accumulation, and the condition that the ratio of gross output per unit of labor matches the average ratio observed in the data of 14.25, can be solved as a four-equation, nonlinear simultaneous equation system in the steady state values of k, m, L, v and the TFP coefficient A. The solutions are: $k=48.38$, $m=0.84$, $L=4.16$, $v=25.31$ and $A=4.45$. Given these, the values of gross output and GDP follow from conventional formulae ($Y \equiv F(mk,L,v)=33.71$, $GDP=59.22$).

The steady-state level of consumption is implied by the product of GDP times the average consumption-GDP ratio taken from the data, $c=0.67GDP=22.56$. The steady-state foreign asset position follows then from the household budget constraint (eq. (2)) evaluated at steady state. The solution is $b=-12.14$. This implies a ratio of external debt to GDP of about 36 percent, which is in line with the estimates produced for Mexico by Lane and Milesi-Ferretti (2001). Finally, the value of γ(the semi-elasticity of the rate of time preference with respect to the argument of utility) follows from the steady-state consumption Euler equation, which implies $\gamma = \frac{\ln(R)}{\ln(1+c-\omega^{-1}L^{\omega})} = 0.024$. As is typical in calibration exercises for small open economies with the SCU specification of preferences (see Mendoza (1991)), the value of the time preference coefficient needed to match the observed debt ratio is very small, indicating that the "impatience effects" introduced by utility function with endogenous rate of time preference are unlikely to introduce quantitatively significant effects on business cycle dynamics.

Markov Process of Exogenous Shocks

Price shocks, TFP shocks and world interest rate shocks follow a joint Markov process with known vectors of realizations and joint transition probability matrix. This Markov process is designed to represent a discrete approximation to a standard vector-autoregression of the cyclical components of the logs of TFP, the gross world interest rate and the world price of intermediate inputs. The approximation is produced using Tauchen's (1991) quadrature procedure. Given that the cyclical components of the three variables have zero mean, the VAR representation of the system is the following:

$$x_{t+1} = RHO \cdot x_t + e_{t,}$$

$$x_t \equiv \begin{bmatrix} \varepsilon_t^A \\ \varepsilon_t^R \\ \varepsilon_t^P \end{bmatrix}, \quad RHO \equiv \begin{bmatrix} \rho_A & \rho_{A,R} & \rho_{A,P} \\ \rho_{R,A} & \rho_R & \rho_{R,P} \\ \rho_{P,A} & \rho_{P,R} & \rho_P \end{bmatrix}, \quad e \equiv \begin{bmatrix} e_t^A \\ e_t^R \\ e_t^P \end{bmatrix} \tag{24}$$

where the errors in the vector *e* are independently and identically distributed with zero mean and a known stationary variance-covariance matrix *cova(e*).

Tauchen's algorithm takes as input *RHO*, *cova(e)* and the desired number of elements of the vector of Markov realizations of each of the three shocks, and it returns as output the vectors of realizations (i.e. the discrete values that each shock can take), the transition probability matrix π across states of the joint Markov process (the transition probabilities across each possible combination of the realizations of each shock), and the associated vector Π of limiting probabilities of each state.

The ideal approach is to estimate the VAR system using actual data and then apply Tauchen's algorithm to construct the discrete Markov process. However, limitations of the Mexican data make it difficult to construct a reliable series of productivity shocks to estimate the VAR. An alternative approach that is some times followed in RBC analysis (see Greenwood et al. (1988) or Mendoza (1991)) is to set the moments of the productivity shocks so as to enable the model to mimic the business cycle moments of GDP. This means imposing restrictions on the elements of *RHO* and *cova(e)*) so that the model matches the observed moments of the cyclical component of GDP (standard deviation, first order-autocorrelation, correlation with interest rate shocks and correlation with price shocks).

Baseline Simulation Results: Economies with and without Credit Constraints

The baseline simulation results compare a variant of the model in which the collateral constraint and the working capital constraint never bind (the "frictionless model") with cases in which the occasionally binding credit constraints are introduced (first the collateral constraint, then the working capital constraint, and finally the two constraints together). A first run of simulation exercises considers a simpler stochastic setup that abstracts from price shocks. In this case, the variability and first-order autocorrelation of interest rate shocks is taken from the data, and the following identifying assumptions are adopted: (1) world interest rate shocks are not affected by lagged Mexican TFP shocks ($\rho_{R,A}$=0) and (2) the innovations to TFP and world interest rate shocks are independent of each other (i.e., *cova(e)* is a diagonal matrix). Results from a VAR of the logged cyclical components of GDP (as a rough proxy for productivity) and the world interest rate support these assumptions. The estimate of $\rho_{R,A}$ is 0.1 with a standard error of 0.06, and the off-main-diagonal elements of *cova(e)* are equal to 0.000025. Given assumptions (1) and (2), the values of $var(e^A)$, ρ_A , $\rho_{A,R}$ and a are set so that the frictionless model matches the standard deviation, first-order autocorrelation, and world-interest-rate correlation of GDP and the standard deviation of investment.[9]

The search for the required values of $var(e^A)$, ρ_A and $\rho_{A,R}$ begins from starting values set to match the corresponding estimates from the VAR in which GDP is used as a proxy for productivity. These starting values are $var(e^A)$=0.000356, ρ_A =0.699 and $\rho_{A,R}$ = -0.092. The

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[9] The rule of "simple persistence" could also be used to specify a joint two-point, symmetric Markov process for TFP and interest-rate shocks that matches the moments of a continuous VAR representation "exactly," avoiding the approximation error of the quadrature algorithm. The drawbacks of this alternative are that simple persistence imposes a common first-order autocorrelation coefficient on both shocks, ρ, and requires the condition $\rho \geq -\left[\frac{1+\rho_{A,R}}{4-\rho_{A,R}}\right]$ to hold. Thus, the lower the value of $\rho_{A,R}$ the higher the values of ρ needed to satisfy the condition (in the limiting case that $\rho_{A,R}$=-1, the condition requires ρ≥0).

same VAR sets values of $var(e^R)$= 0.000215 and ρ_R=0.238. These values of $var(e^R)$ and ρ_R yield an interest rate process with 1.56 percent standard deviation and 0.238 autocorrelation, which are very close to the corresponding moments reported in Table 1 for the world interest rate (1.60 and 0.276 respectively). This reflects the fact that the coefficient on lagged GDP in the interest rate regression and the off-main diagonal elements of *cova(e)* are all insignificantly different from zero.

The above initial specification of the VAR system is passed through Tauchen's algorithm to obtain a Markov representation with two realizations for ε^A and ε^R. This Markov process, along with an initial value for the investment adjustment cost a and the rest of the calibrated parameters, are then used to solve the model to obtain the implied standard deviation, first-order autocorrelation and interest-rate correlation of GDP and the standard deviation of investment in the stochastic steady state. These moments are compared with the corresponding moments from the data reported in Table 1. The values of $var(e^A)$, ρ_A, $\rho_{A,R}$ and a can then be re-set (and the process repeated) to bring the model closer to the "target" moments from the data. The model matches the four target moments with a value of a=0.27 and the VAR parameters set to $var(e^A)$=0.000075, ρ_A =0.65 and $\rho_{A,R}$ =0.1.[10] The resulting joint Markov process is as follows:

$$\varepsilon^A = \begin{bmatrix} -0.00866 \\ 0.00866 \end{bmatrix}, \; \varepsilon^R = \begin{bmatrix} -0.014663 \\ 0.014663 \end{bmatrix}, \; \pi = \begin{bmatrix} 0.52 & 0.10 & 0.32 & 0.06 \\ 0.17 & 0.45 & 0.11 & 0.28 \\ 0.28 & 0.11 & 0.45 & 0.17 \\ 0.06 & 0.32 & 0.10 & 0.52 \end{bmatrix}, \; \Pi = \begin{bmatrix} 0.26 \\ 0.24 \\ 0.24 \\ 0.26 \end{bmatrix}.$$

The numerical solution of the Bellman equation for this version of the model uses discrete grids with 52 evenly-spaced nodes spanning the interval [44.24,51.49] in the grid of capital stocks and 64 evenly-spaced nodes spanning the interval [-41.07,18.78] in the grid of

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[10] Note that the moments of the interest rate shocks and the productivity shocks do not match exactly those implied by the VAR model because of the error of the quadrature approximation. This error can be reduced by increasing the number of realizations of each shock in the Markov process but at a high cost in computing time.

foreign asset positions. Since there are two realizations of each shock, there are four states for the exogenous shocks made of the four doubles in which the two values of each shock can be combined. Hence, the discrete state space over which the Bellman equation is solved consists of 52x64x4 coordinates that represent all possible combinations of values of *k*, *b* and the shocks.[11]

The statistical moments that characterize "normal" business cycles in the stochastic steady state of the frictionless economy are reported in Panel I of Table 2. These moments are computed using the corresponding limiting distribution of *k*, *b*, and the exogenous shocks. The moments of Table 2 are consistent with standard features of RBC models, although they are not a close match to some of the moments from Mexican data reported in Table 1. Consumption is less volatile than GDP, investment is more volatile than GDP, consumption and investment are procyclical and they display positive persistence.

As indicated earlier, the frictionless model is a variant of the standard small-open-economy RBC model that cannot produce Sudden Stops because it assumes that credit markets are perfect. In particular, as the quantitative results that follow will show, the economy responds to adverse realizations of productivity and interest rate shocks with a relatively smooth adjustment of the current account and "regular" recessions in absorption and production, regardless of the size of household debt and working capital financing or the ratios at which these obligations are leveraged on the value of assets or gross sales.

Panels II, III and IV of Table 2 show the business cycle moments for the same model calibration as the frictionless economy except that the assumption of perfect credit markets is removed. Panel II reports results for the economy with a collateral constraint that limits household debt not to exceed 40 percent of the market value of physical assets (i.e., κ=0.4). This

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[11] Results produced using grids with 86 evenly-spaced points spanning the same intervals were compared with the results of the 52x64 simulation. They show negligible differences in the first and second moments of the endogenous variables computed with the ergodic distribution.

value of the "margin coefficient" was set so as to approximate the observed frequency of Sudden Stops in the data. Since only one quarterly observation for 1995 yields deviations below trend of the business cycle indicators larger in absolute value than two standard deviations of the corresponding series, the measured probability of Sudden Stops in the 1980:1-2002:4 sample is 1/92 or 1.1 percent. The limiting distribution for the model economy with κ=0.4 shows that the economy reaches states of nature in which the collateral constraint binds with 1.8 percent probability. This occurs after non-zero probability sequences of realizations of the shocks lead the economy to levels of leverage in which the ratio of debt to the market value of capital approaches 40 percent. Because of the curvature of the constant-relative-risk-aversion period utility function, households are highly averse to the drastic consumption adjustments implied by Sudden Stops, and hence they have an incentive to engage in precautionary savings and hence minimize their exposure to the risk of Sudden Stops. This rules out from the stochastic steady state of the economy with the collateral constraint states of nature with levels of capital and debt that would support leverage ratios as high as 90 percent in the limiting distribution of the frictionless economy. As a result, the business cycle indicators reported in Panel II of Table 2 show negligible differences compared to those of the frictionless economy shown in Panel I.

The finding that Panels I and II show similar business cycle moments shows that the model with collateral constraints produces "normal" business cycles with similar features as the frictionless economy. The next task is to show that nested within this "normal" cycles are "unusually large" recessions that occur when the economy suffers a Sudden Stop. To show that this is the case, Figures 4.a and 4.b show the forecasting functions (or conditional impulse responses) of macroeconomic aggregates in response to combined one-standard-deviation shocks to productivity and the world interest rate for the frictionless model and the model with collateral constraints. The forecasting functions are conditional on an initial condition of high leverage inside the region of the state space in which adverse shocks trigger a Sudden Stop with positive long-run probability. The economy with collateral constraints hits this particular coordinate of the state space with a probability of 0.0067 percent. The solid line of each plot in the Figures shows the forecasting functions of the frictionless economy and the dashed line those pertaining to the economy with collateral constraint (both as a percent deviations from the mean of the frictionless economy).

The comparison of the forecasting functions for the frictionless model and the model with the collateral constraint shows that when adverse shocks trigger the constraint, the economy displays deeper and more persistent recessions. There is no difference in the contemporaneous effects on output and factor demands in Figure 4.a because the initial capital stock is predetermined and identical in both model economies, and because the realizations of the shocks are also identical. In contrast, the impact effects on consumption, investment, the Tobin q and the external accounts shown in Figure 4.b are strikingly different when the collateral constraint binds. The initial decline in consumption is about 1 percentage point larger. Investment declines about 25 percent instead of showing a modest increase, reflecting a similar pattern in the response of the Tobin q that falls by nearly 0.8 percent instead of rising 0.2 percent. The current account-GDP ratio increases by 3 percentage points instead of falling 3 percentage points, and the trade balance-GDP ratio rises by nearly 6 percentage points instead of falling slightly.

Output and factor utilization display larger and more persistent declines starting one period after the shocks hit. As Figure 4.a shows, GDP, use of intermediate inputs, labor and capital are 1.5 to 2 percentage points lower in the economy with collateral constraints 4 quarters after the shocks hit the economy, and it takes over 20 quarters for these variables to converge to the levels of the frictionless economy (working capital financing in Figure 4.b shows the same pattern). The shocks induce firms to substitute away from factor demands into more intensive use of existing inputs by increasing the rate of capacity utilization by as much as a quarter of a percent, and this increase also takes about 20 quarters to be reversed. The increase in utilization tends to offset the adverse output effects of the shocks, and hence in the model with collateral constraints it is a force that weakens Sudden Stops.

Figure 4.b shows that a Sudden Stop induces a tilt of the time profile of consumption, with lower consumption than in the frictionless economy for the first 12 quarters after the shocks hit, converging thereafter to a slightly higher consumption level (as indicated by the small difference in mean consumption levels in Panels I and II of Table 2). The Figure also shows that the large immediate adjustments in investment, the Tobin q and the external accounts are relatively short lived, compared with the persistent effects on output and factor usage. The differences between the frictionless economy and the economy with collateral constraints in the forecasting functions of these variables become very small 6 quarters after the initial shocks.

Kocherlakota (2000) argued that in examining the business cycle implications of credit constraints, it is important to separate measures of persistent effects that result from "sufficiently adverse" shocks that trigger the constraints, as illustrated in Figures 4.a and 4.b, from measures of amplification effects, that quantify how much larger are business cycles because of the presence of the binding credit constraints.[12] He proposed as a measure of amplification the absolute value of the difference between output in the second period after a once-and-for-all, linear income shock hits and steady-state output relative to the size of the shock (and the same for the price of land but as of the first period). Fixing the labor share at 60 percent and varying the shares of capital (land) in production from 10 to 30 (30 to 10) percent in a setup in which

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[12] Kocherlakota also noted that the effects of the credit constraints are asymmetric, because there are larger and more persistent recessions in response to adverse shocks but the opposite does not occur with favorable shocks.

labor and land are in inelastic supply, he found small amplification effects (at most 0.8 percent for the price of land and 34.9 percent for output).

In this paper, magnification is measured as the difference between the values of the variables in the frictionless economy and those pertaining to the economy with collateral constraints relative to the standard deviation of each variable in the frictionless economy (i.e., this coefficient measures how much deeper are the recessions of a Sudden Stop in units of the standard deviations that measure "normal" business cycles). The top charts of Figures 5-8 plot the magnification effects on GDP, consumption, the current account-GDP ratio and the Tobin q for each of the first 20 quarters after adverse TFP and interest-rate shocks hit the economy (with the same initial conditions used for the forecasting functions of Figures 4.a and 4.b). These magnification effects are significantly larger than those estimated by Kocherlakota. The output magnification effect at date 2 is 50 percent (Figure 5) and the one for the price of capital (Figure 8) is about 275 percent. These estimates imply that GDP (the price of capital) is lower in the economy with collateral constraints than in the frictionless economy by a deviation from the mean that is 0.5 (2.75) times larger than the standard deviation of the price of capital in the frictionless economy. Moreover, magnification effects do not necessarily peak at date 2 (the magnification effect on GDP peaks on date 4 at about 56 percent) and there are sizable magnification effects at date 1 on consumption and the current-account GDP ratio.

The simulation results for the economy with the collateral constraint capture several interesting features of a Sudden Stop. They show that unusually large and persistent recessions can take place in response to shocks of "standard" magnitude when the economy is highly leveraged, and that these Sudden Stops are nested within smoother "normal" business cycles that dominate standard business cycle moments. The results also show that the economy can arrive with positive long-run probability at these high-leverage states, and that persistence and magnification effects on business cycles induced by credit constraints can be large. However, there are also some important flaws. The model does not do a good job at matching some of the long-run business cycle moments. More importantly, it produces two strongly counterfactual outcomes. First, output, factor demands, capacity utilization and working capital financing do not respond on impact when a Sudden Stop hits the economy. Second, capacity utilization rises above its long-run mean during the entire deeper, more persistent recession of a Sudden Stop. The results of simulations that activate the working capital constraint and that put the two constraints to work together show that adding the working capital constraint can allow the model to address these problems.

Panels III and IV of Table 2 report the business cycle moments for the model with the working capital constraint and the model with both the collateral constraint and the working capital constraint. Figures 9.a and 9.b show the conditional forecasting functions for these model simulations, using the same initial conditions as before. The results for the models with perfect credit markets and with the collateral constraint alone are also reproduced in these plots to facilitate comparisons. The middle and bottom charts of Figures 5-8 show the magnification effects for the model with the working capital constraint and the model with both constraints.

A comparison of Panels III and IV with Panel I in Table 1 shows again that the "occasionally binding" credit constraints have small effects on the long-run business cycle statistics. Figures 9.a and 9.b show that despite the potential for general equilibrium feedback effects, the working capital constraint and the collateral constraint have largely independent effects. The dynamics of foreign assets, capital, investment, the Tobin q and the external accounts are nearly invariant to the addition of the working capital constraint, whereas those of GDP, factor demands, capacity utilization and working capital change significantly. The main change is that now there are sizable contemporaneous effects in response to the TFP and interest rate shocks. GDP and labor fall by an additional 1.5 percentage points when the shocks first hit the economy, while intermediate goods drops 5 percentage points more and capacity utilization falls by a half of a percent. The deviations from mean of these variables, with the exception of capacity utilization, follow a monotonic, concave path to their long-run equilibrium.

The working capital constraint eliminates the counterfactual response of capacity utilization found in the model with the collateral constraint. In the model with working capital constraint only, utilization recovers from the large initial hit but remains always below the mean of the frictionless model. In the model with the two constraints, utilization takes a similar initial hit and it never rises above its own long-run mean in the model with the two constraints (which puts it permanently below the mean of the frictionless model by about 0.2 percent).

Interestingly, the impact effect on consumption (a decline of about 7 percent) is similar with the collateral constraint and the working capital constraint. After that, consumption in the latter increases faster until about the eight quarter, and from then on consumption in the former rises faster and converges to a higher long run mean (as confirmed by the consumption means reported in Panels II and III of Table 1).

It is important to note that assumptions about the production technology and the nature of the working capital constraint imply that the mechanism that triggers this constraint is significantly different from the one that triggers the collateral constraint. The working capital constraint sets a limit on working capital financing as a fraction of sales (or gross output) net of wage costs. However, with a Cobb-Douglas technology and competitive factor pricing, the ratio of working capital financing to sales net of labor costs depends only on the realization of the interest rate shock and a set of exogenous parameters (the factor shares of the production function, the curvature parameter of the cost of capital utilization, and the fraction of costs of intermediate inputs and costs of utilization paid in advance of production). Thus, by construction shocks to productivity or intermediate goods prices, as well as the values of the endogenous states *k* and *b*, cannot affect the working capital constraint. Given the two-point structure of the Markov vector of interest rate shocks, the simulation with working capital constraint yields a binding working capital constraint when the interest rate is high and a non-binding constraint when it is low. This implies that by definition the working capital constraint binds 50 percent of the time in the limiting distribution. Adding more points to the Markov vector of interest rate shocks can reduce this probability, but the fact that the constraint is triggered only by interest rate shocks, regardless of the values of all other state variables, is unaltered. In contrast, the collateral constraint can be triggered by all the exogenous shocks of the model, and adverse shocks by themselves are not sufficient to trigger the constraint – they need to hit the economy when the ratio of debt to value of capital is sufficiently high, and this ratio is a function of the endogenous stochastic dynamics of the economy.

The collateral constraint also differs in that it features the Fisherian debt-deflation mechanism explained in Section 3. This mechanism plays an important role in driving the magnification effects of the collateral constraint. Figures 10-13 illustrate this point. Figures 10 and 11 are three-dimensional manifolds that show the consumption impact effects (measured as deviations from the long-run mean) on the date that adverse one-percent-standard-deviation shocks to TFP and the interest rate hit the economy, as functions of the values of *k* and *b* as of that date. Figure 10 is for the economy with collateral constraints, while Figure 11 is for the economy with perfect credit market. Figures 12 and 13 are analogous plots that show the impact effects on Tobin's q. The flat regions for the lowest values of *b* in Figures 10 and 12 correspond to *(k,b)* combinations that become non-feasible for the economy with the collateral constraint.

Figures 10 and 11 illustrate the large drops in consumption in response to adverse one-standard-deviation shocks to TFP and the world interest rate when the collateral constraint binds.

Figure 10 shows that the consumption collapses caused by adverse shocks when the economy is highly leveraged (i.e., when debt is large relative to capital, or when *b* is low relative to the market value of *k*) are much larger than the consumption recessions that the same shocks cause when the economy's level of leverage is low. A comparison of Figures 10 and 11 shows that for high values of *b* consumption in the two economies responds on impact in nearly the same way to the adverse shocks, while in states of high leverage consumption in the economy with collateral constraints suffers a major collapse. Coordinates below the 24th point in the *b* grid have zero probability in the limiting distribution of the economy with collateral constraint, illustrating again the point that precautionary savings prevents the largest Sudden Stops from taking place in the long-run equilibrium. However, even when the initial state of *b* is in its 24th or 25th grid value, large consumption collapses do take place.

Figures 12 and 13 show the effects of the Fisherian debt-deflation mechanism. Adverse shocks to TFP and the interest rate cause small declines in the price of capital when credit markets are perfect (Figure 13) or when there is potential for margin calls but leverage ratios are low (Figure 12 for high values of *b*). When debt is sufficiently high, the same adverse shocks trigger the collateral constraint and this results in agents being required to sell capital (as if they were fire-selling assets to meet margin calls). The price of capital thus sinks below the value that would have prevailed in the economy with perfect credit markets, but this tightens further the collateral constraint, inducing agents to reduce further their capital investments and cause further price declines. Figure 12 shows the end result of this process. The downward spiral in the price of capital is hampered by the capital adjustment cost and the future output loss that the implied reduction in investment would cause, but even so there are still states of nature at *t* in which agents may seek to reduce their capital holdings for *t+1* down to the lowest feasible value of *k* (i.e., the first value in the capital grid). This can be inferred from the area of Figure 12 in which the price impact effect behaves like a smooth linear, negative function of the capital stock at *t*. For all these coordinates of the state space, capital at *t+1* falls to the lowest value of the *k* grid when the adverse shocks hit and the collateral constraint is triggered. The resulting price decline is larger the larger the distance between k_t and the lowest *k* in the grid. This lower bound in capital holdings can be interpreted as if agents were hitting a constraint on equity sales. However, this constraint would not bind in the long run because in the limiting probability distribution of the economy with collateral constraint the lowest value in the *k* grid that has non-zero probability of being observed is the 7th coordinate. Thus, the states of nature with the largest equity price collapses and largest downward investment responses are again ruled out in the long run by precautionary savings.

5. Conclusions

This paper explores the extent to which an open economy equilibrium business cycle model with imperfect credit markets can account for the Sudden Stop phenomenon of recent emerging markets crises. The perfect international credit market typical of real-business-cycle models of the small open economy is replaced with a credit market that features a collateral constraint, which limits debt not to exceed a fraction of the value of the economy's physical assets, and a working capital constraint, which limits working capital financing not to exceed a fraction of sales net of labor costs. These constraints only bind in states of nature in which the economy's financial liabilities (debt and working capital financing) are sufficiently high relative to the values of assets and incomes on which they are leveraged. The economy arrives at these high-leverage states in which it is vulnerable to a Sudden Stop with positive probability even in the long run and despite precautionary-savings incentives to avoid large debt positions. These high-leverage states are the endogenous outcome of the economy's stochastic competitive equilibrium dynamics in response to exogenous random shocks to productivity, the world interest rate, and the price of imported intermediate goods.

The motivation to introduce collateral and working capital constraints simultaneously comes from observations from emerging markets data, particularly the Mexican Sudden Stop of 1995. These data suggests that explanations of the Sudden Stop phenomenon need to reconcile two stylized facts. First, the sudden reversal of the current account, the loss of access to credit markets, and the collapse of equity prices indicate that Sudden Stops are “unusually” deep recessions triggered by a financial phenomenon. Second, changes in use of intermediate inputs, capacity utilization and TFP account for the bulk of the “unusually” large output collapse that occurs at the same time world credit market access is lost, while drops in investment, even if substantial, play a smaller role. Thus, on one hand explanations of the Sudden Stop phenomenon need to link credit market frictions to changes in intermediate inputs and capacity utilization, and on the other hand they need to incorporate mechanisms that allow those frictions to trigger larger and more persistent recessions than the typical recessions observed when credit market access is not compromised. In the model of this paper, the working capital constraint provides the link between financial frictions and factor demands and capacity utilization, and the collateral constraint introduces the mechanism for magnification and propagation of the business cycle response of the economy to adverse exogenous shocks.

The business cycle model developed in this paper produces Sudden Stops as infrequent events nested within “regular” business cycles, and those Sudden Stops are triggered by real shocks of the same magnitude as those that drive “regular cycles.” In simulations calibrated to Mexican data, the long-run business cycle moments of model economies with and without credit constraints differ by small margins, while the predicted mean responses to one-percent-standard-deviation shocks starting from an initial condition of high leverage differ sharply and reproduce several of the observed features of Sudden Stops. Magnification effects on the responses of macroeconomic aggregates to exogenous shocks are significantly larger than those that previous studies of the role of credit constraints in creating business cycles suggest (see Kocherlakota (2000)). Thus, this paper shows that explanations of Sudden Stops need not rely on large and/or unexpected shocks, and that is possible to use credit constraints to integrate a theory of "regular" business cycles with a theory of Sudden Stops within the same dynamic, stochastic general equilibrium framework. This is done without relying on multiplicity of equilibria or non-neutralities produced by nominal rigidities.

The collateral constraint and the working capital constraint introduce three credit channel effects. Two of these effects are in the form of endogenous external financing premia that emerge when the credit constraints bind. These premia reflect the "effective" (or shadow) real interest rates that lead households and firms to choose levels of debt and working capital that satisfy their credit constraints as levels that are also consistent with their optimal plans. Thus, even though the credit constraints are not derived as features of an optimal contract, these external financing premia are analogous to endogenous risk premia that a risk-neutral lender would charge to be exposed to default risk in an environment in which limited enforcement allows the lender to confiscate only the fractions of the value of physical assets or gross sales net of labor costs specified by the credit constraints.

The third credit channel effect is the Fisherian debt-deflation mechanism associated with the collateral constraint. This mechanism plays a key role in the ability of the model to enlarge and increase the persistence of the real effects of exogenous shocks. In a high-leverage state of the economy with the collateral constraint, adverse shocks that would result in a small equity price decline with perfect credit markets trigger the collateral constraint causing a fall in physical investment (i.e., a fire-sale of capital) and a fall in equity prices that tightens further the credit constraint. The end result of this deflationary spiral is a much larger drop in equity prices and physical investment than in the economy with perfect credit markets.

The analysis is still incomplete in several parts. The model has important limitations in accounting for several quantitative features of the data. In particular, the current account is not countercyclical in the model simulations and the asset price collapses, even though much larger with the credit constraints than without them, are still too small compared to actual asset price collapses. This can be partly due to the fact that the simulations reported here include only TFP and interest rate shocks, and thus need to be updated to introduce shocks to intermediate goods prices. These price shocks are large and highly persistent in the data, and thus they are likely to enlarge the price collapses and reduce the correlation between the current account and GDP.

Another important limitation is that the model does not feature one key aspect of the financial transmission mechanism that seems to have been at work in emerging markets crises: the "liability dollarization effect" induced by the fact that the foreign debt of emerging economies is denominated in hard currencies (i.e. tradables goods units) but largely leveraged on assets and incomes in domestic currencies and generated by non-tradables industries. As a result, a fall in the relative price of nontradables increases the effective the real interest rate, and a sharp relative price collapse can trigger financial collapse. One option to introduce this into the model would be to incorporate fully consumption and production decisions for nontradables. However, since the key aspects of the "liability dollarization" effect are (1) the difference in the units in which debt contracts and incomes and assets securing those contracts are denominated, and (2) sharp movements in the relative price of those two units, the "liability dollarization" effect could be introduced via changes in prices of intermediate goods imports. In fact, the Mexican data show that the sudden rise in the relative price of intermediate goods was much larger and more persistent than the drop in the relative price of nontradables. Adding this feature to the model requires denominating foreign debt in units of a world tradable good that is the same numeraire as for intermediate goods imports. In this case, a sharp increase in intermediate goods prices will not only increase the direct input cost of intermediate goods but also the financing cost of all financial contracts. This extension is planned for future research.

The findings of this paper suggest that the key to reducing the probability of Sudden Stops in emerging economies is in promoting the attainment of levels of financial development that *lower* collateral and working capital constraints. Taking as given the underlying uncertainty driving business cycles in the form of aggregate, non-insurable shocks to TFP, world interest rates and relative prices, tighter credit limits designed to manage exposure to idiosyncratic risk can be counterproductive and lead to a higher probability of observing Sudden Stops.

A second policy conclusion relates to financial contagion. In the setup of this paper, an emerging economy can have solid domestic policy and competitive, open markets, and still reach a point of high leverage at which a Sudden Stop is caused by an increase in the world interest rate induced by developments elsewhere in the world. If waiting for financial development is a costly alternative and tighter credit limits can make things worse, an alternative to explore is to use international financial organizations to help emerging markets maintain access to credit in these situations of financial contagion (see, for example, Calvo's (2002) proposal).

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Figure 1. Mexico: Real GDP Per Capita 1920-2001
(logarithms with Hodrick-Prescott trend)

Figure 2. Mexico: Current Account-GDP Ratio
(quarterly data at annual rates)

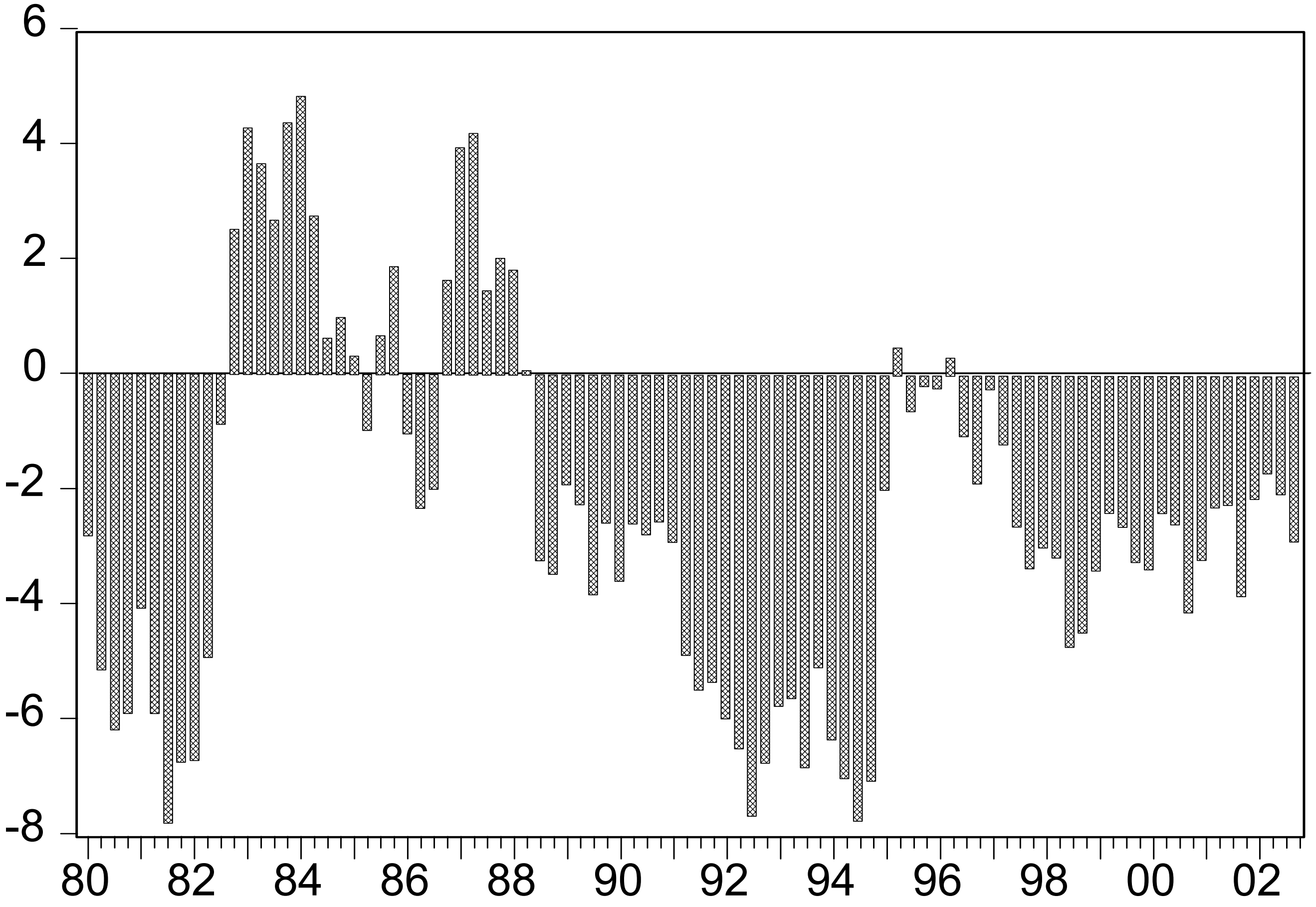


Figure 3. Mexico: Real Prices of Equity, Imports of Intermediate Goods and Nontradable Goods

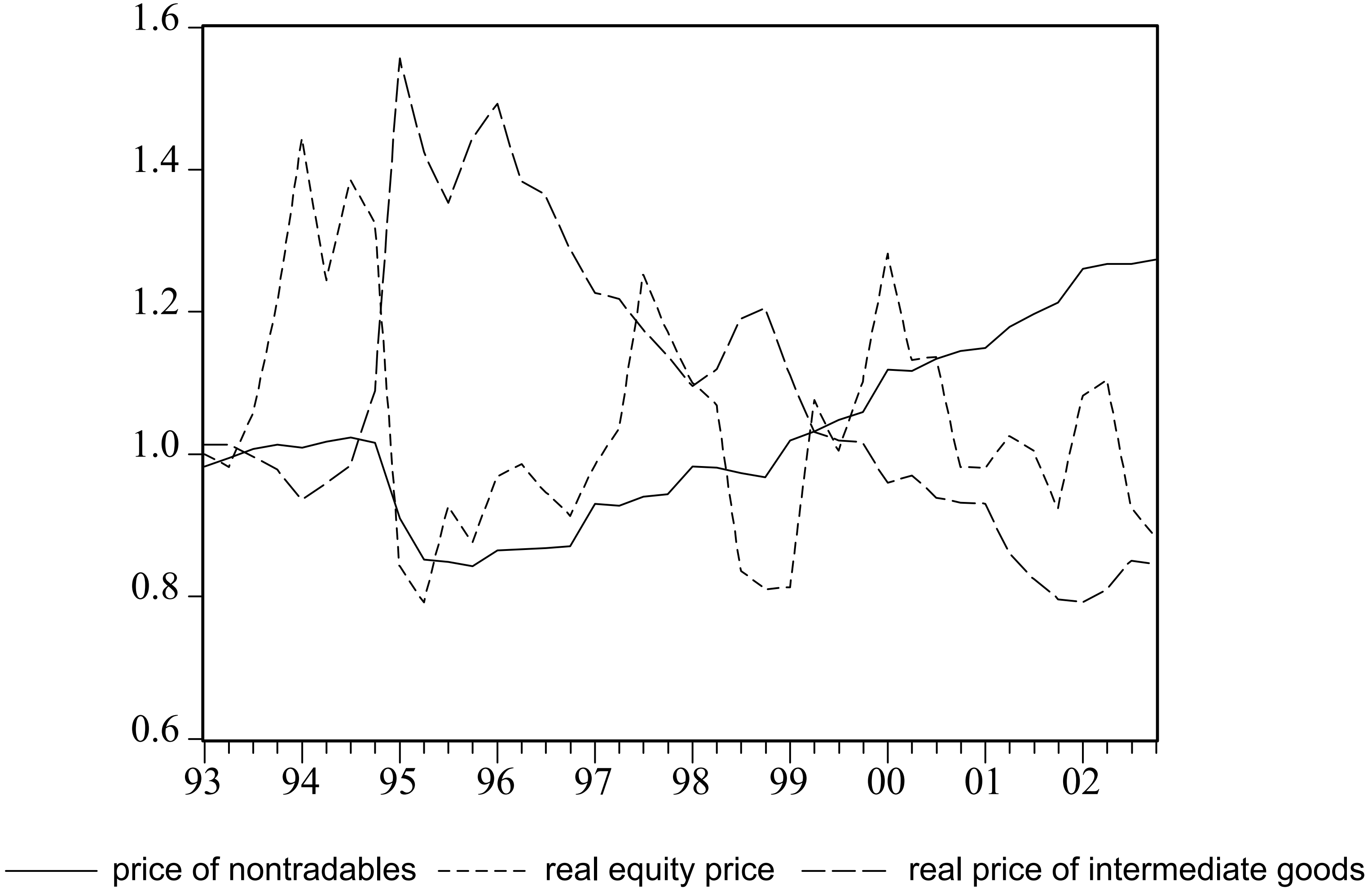
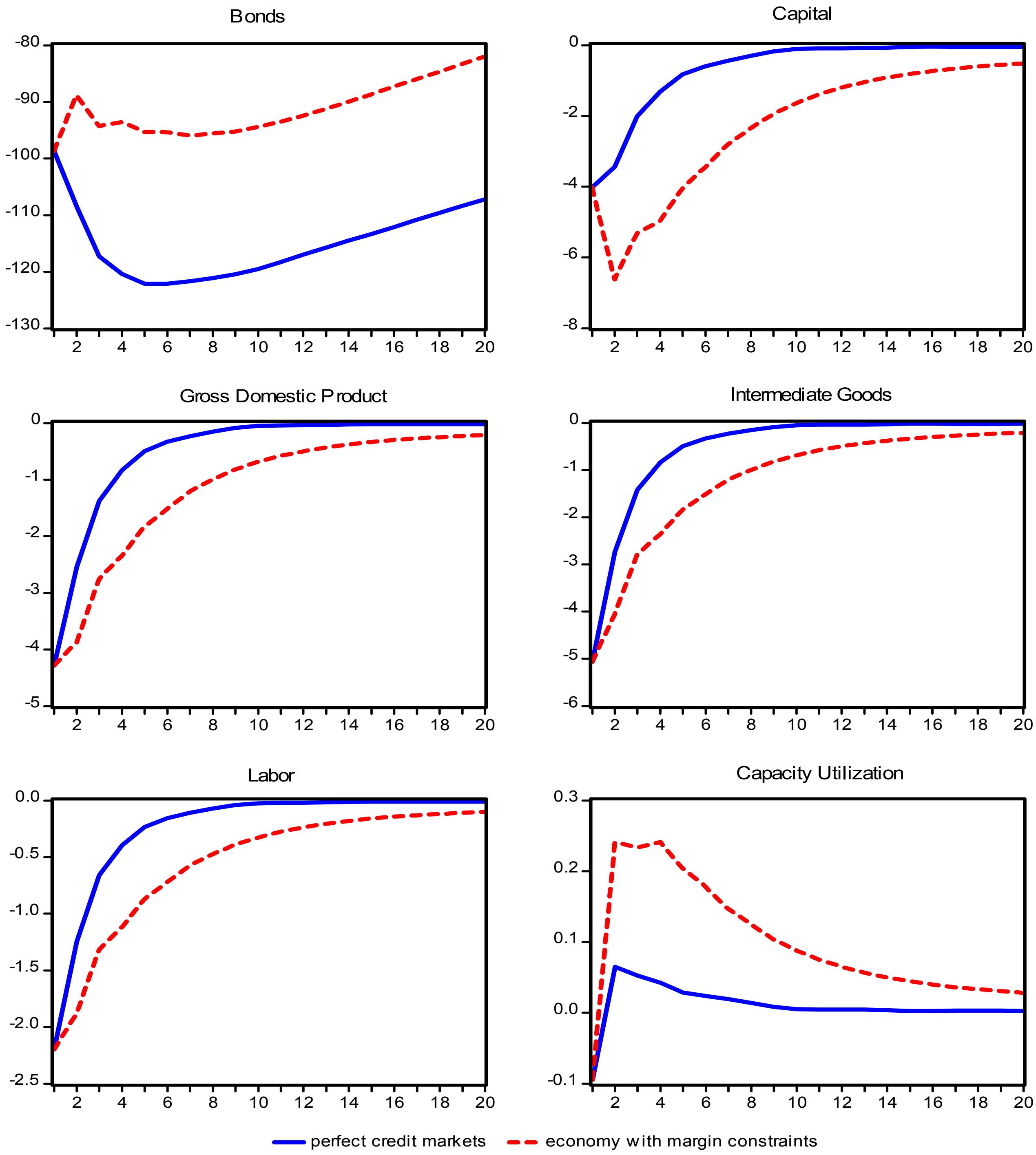
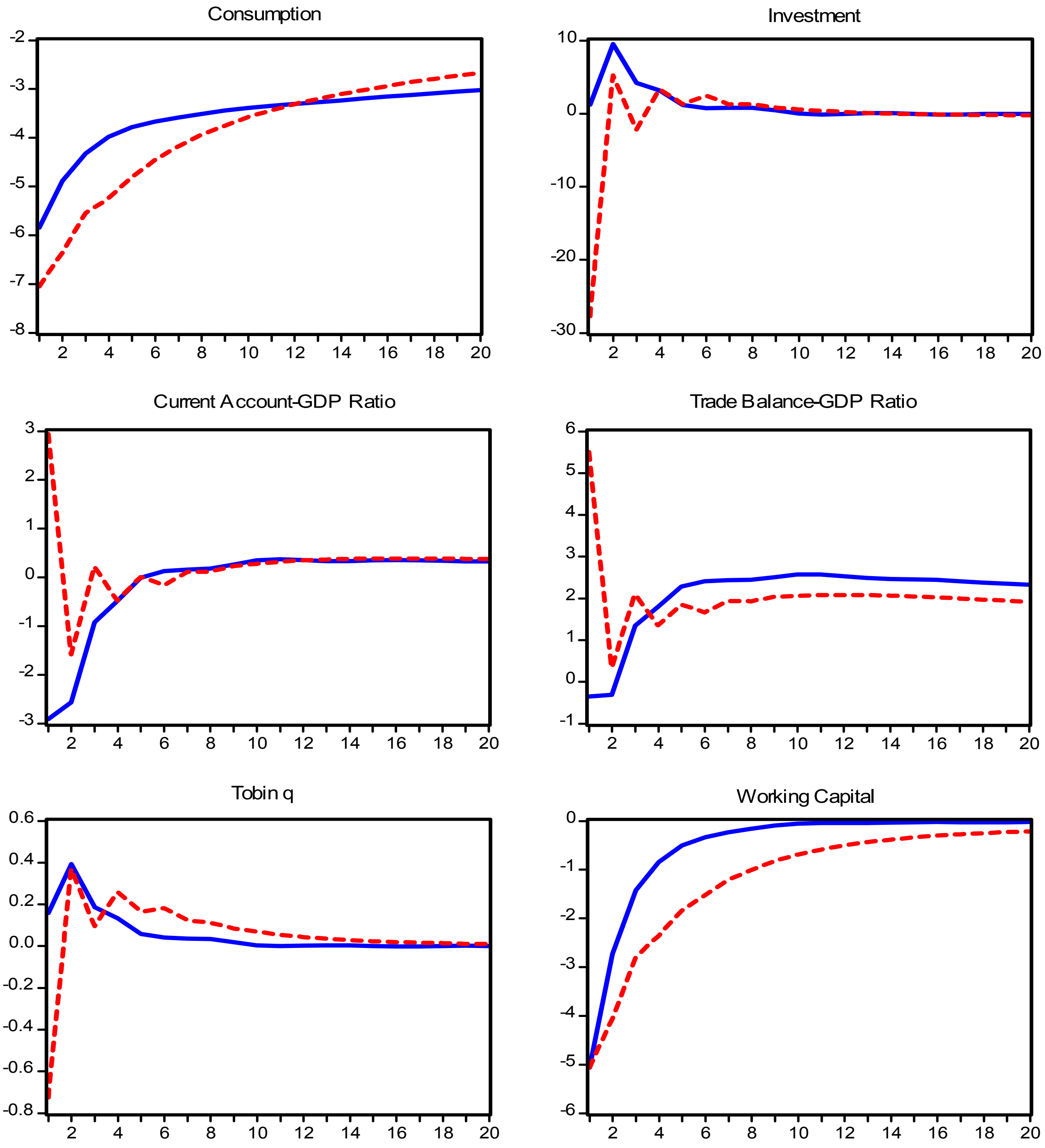


Figure 4.a Conditional Forecasting Functions in Response to Adverse One-Standard-Deviation Shocks to Productivity and World Interest Rate
(percent deviations from long-run means)



Note: Forecasting functions are conditional on the initial conditions K=47.08, B=-19.22 with productivity in its low state and the world interest rate in its high state.

Figure 4.b Conditional Forecasting Functions in Response to Adverse One-Standard-Deviation Shocks to Productivity and World Interest Rate
(percent deviations from long-run means)



Note: Forecasting functions are conditional on the initial conditions K=47.08, B=-19.22 with productivity in its low state and the world interest rate in its high state.

Figure 5. Output Magnification Effects of Financial Constraints
(in percent of standard deviation under perfect credit markets)

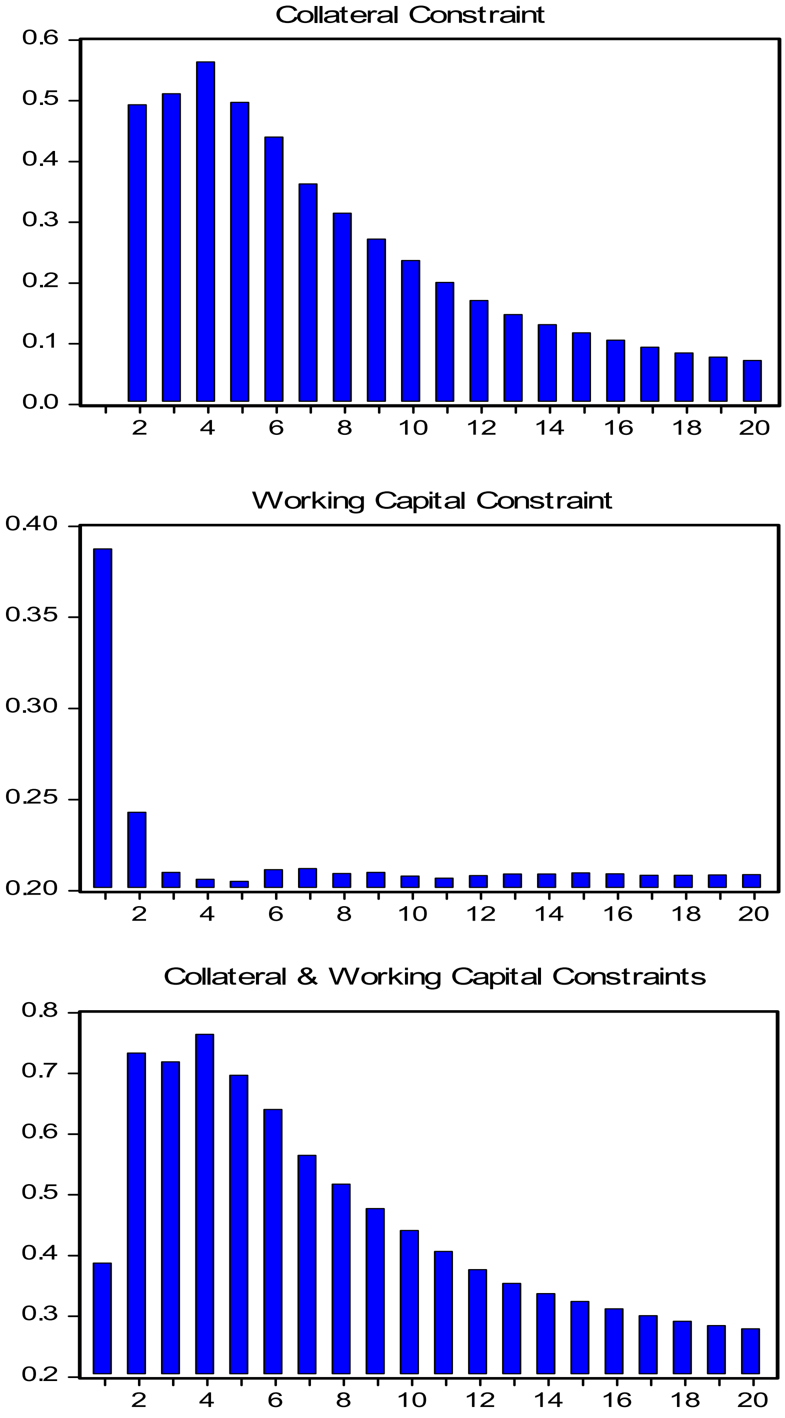
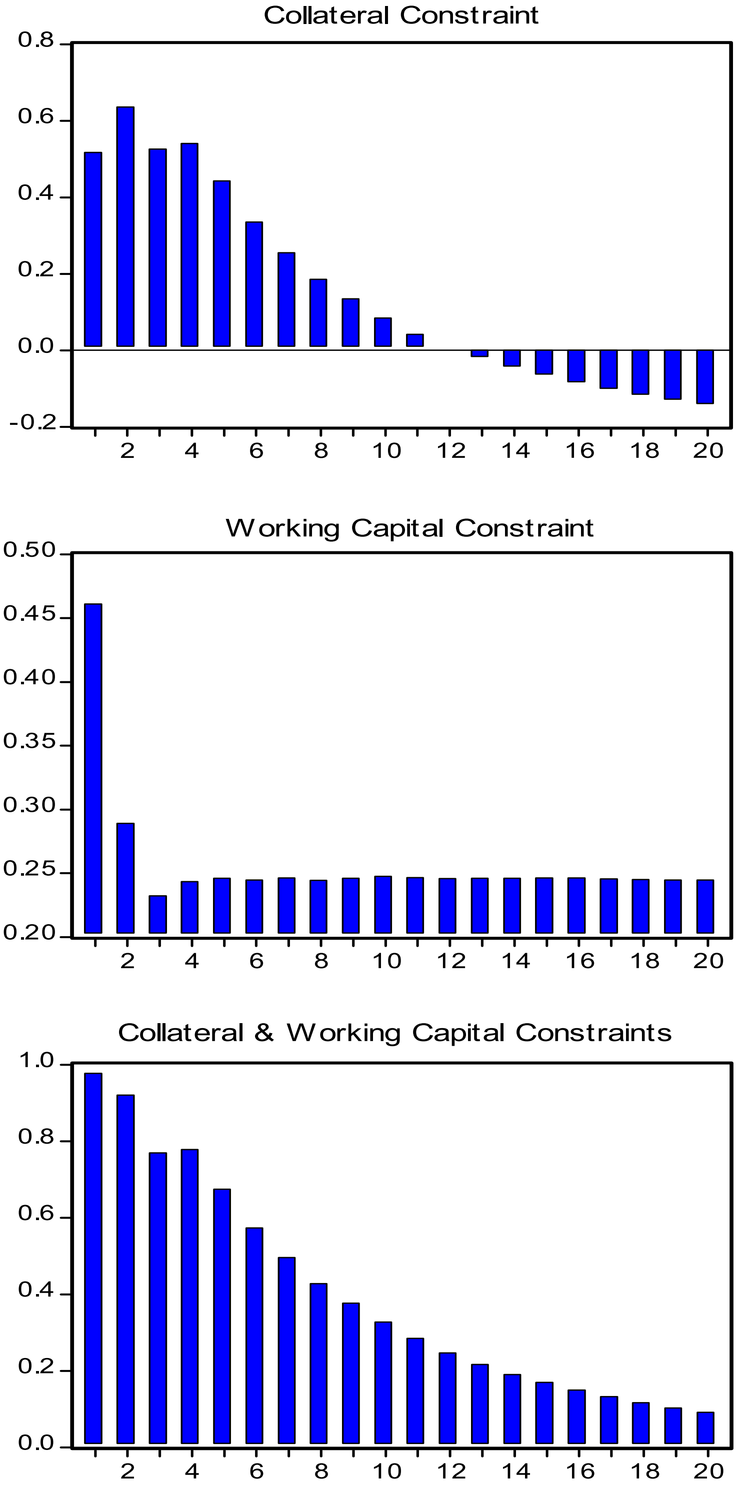


Figure 6. Consumption Magnification Effects of Financial Constraints
(in percent of standard deviation under perfect credit markets)

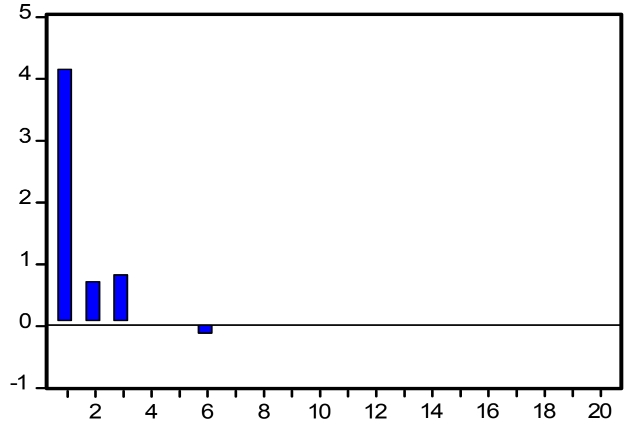


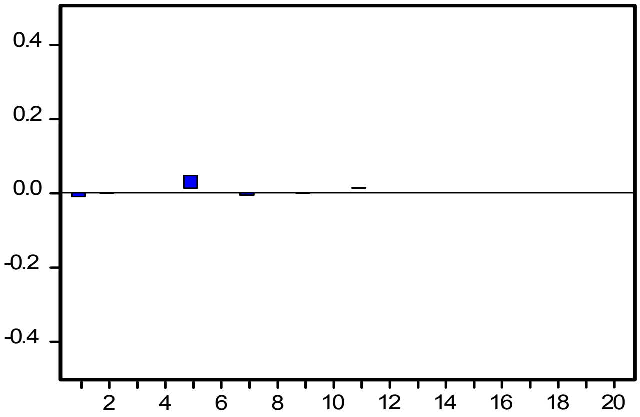
Collateral Constraint

Working Capital Constraint

Collateral & Working Capital Constraints

Figure 7. Current Account-GDP Ratio Magnification Effects of Financial Constraints
(in percent of standard deviation under perfect credit markets)


Collateral Constraint


Working Capital Constraint

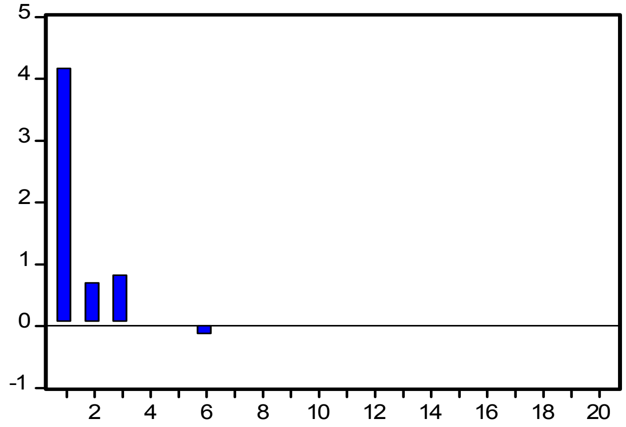
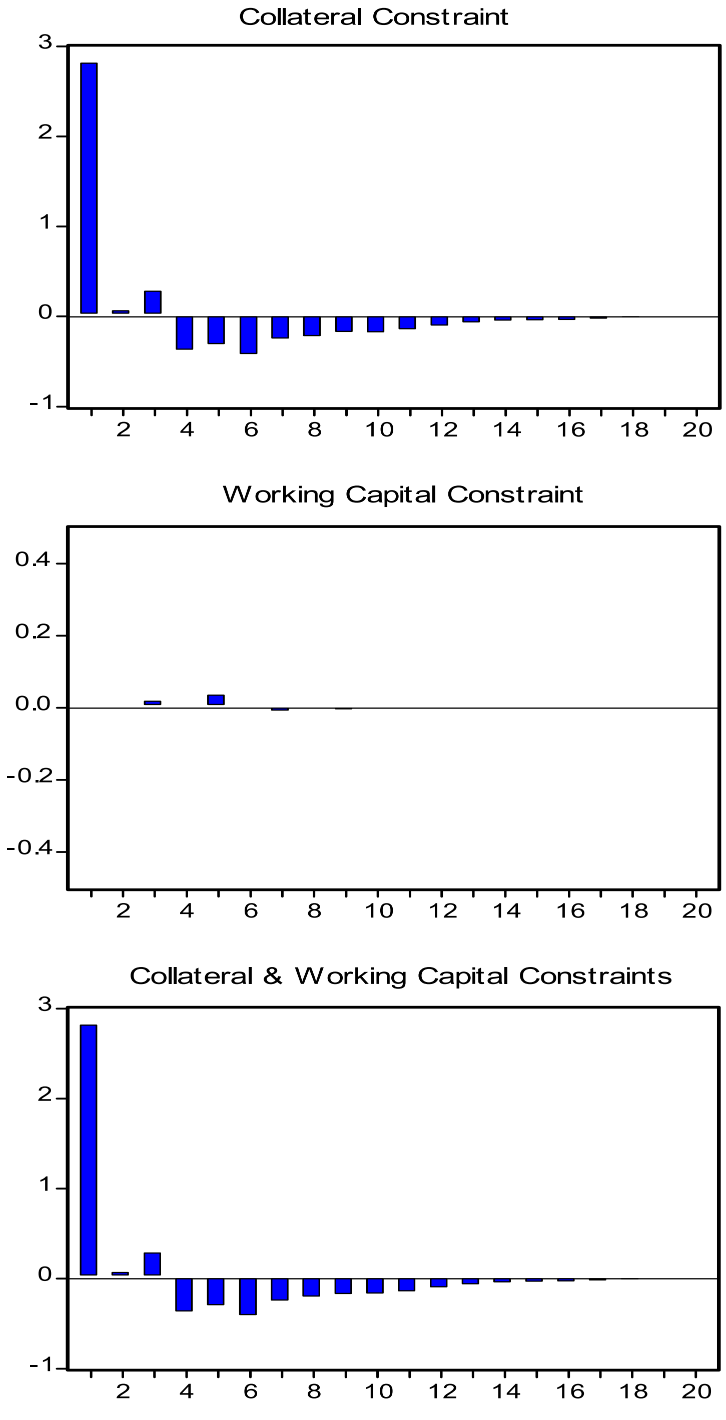

Collateral & Working Capital Constraint

Figure 8. Equity Price Magnification Effects of Financial Constraints
(in percent of standard deviation under perfect credit markets)

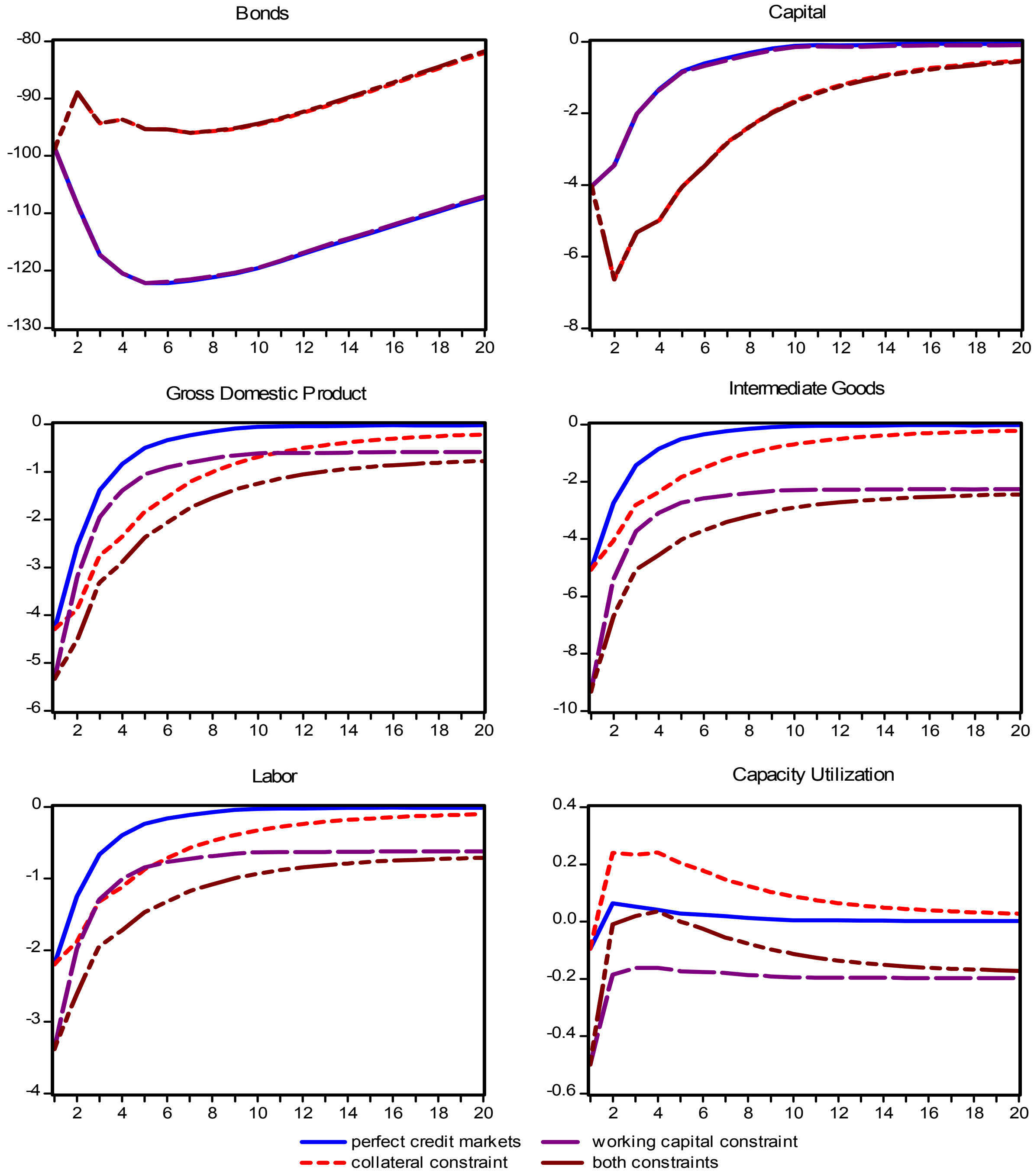


Collateral Constraint

Working Capital Constraint

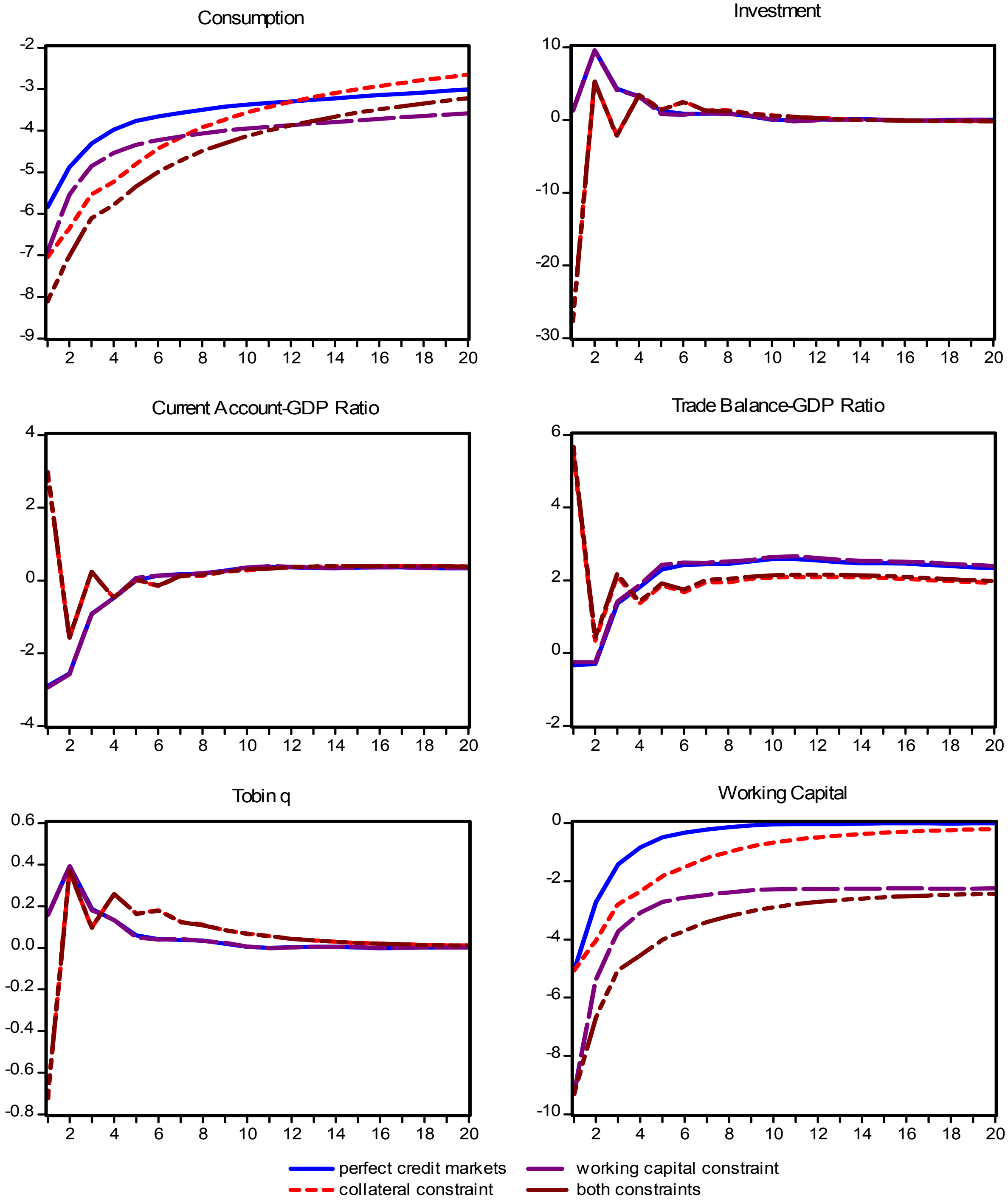
Collateral & Working Capital Constraints

Figure 9.a Conditional Forecasting Functions in Response to Adverse One-Standard-Deviation Shocks to Productivity and World Interest Rate
(percent deviations from long-run means)



Note: Forecasting functions are conditional on the initial conditions K=47.08, B=-19.22 with productivity in its low state and the world interest rate in its high state.

Figure 9.b Conditional Forecasting Functions in Response to Adverse One-Standard-Deviation Shocks to Productivity and World Interest Rate - continued
(percent deviations from long-run means)



Consumption

Investment

Current Account-GDP Ratio

Trade Balance-GDP Ratio

Tobin q

Working Capital

Note: Forecasting functions are conditional on the initial conditions K=47.08, B=-19.22 with productivity in its low state and the world interest rate in its high state.

Figure 10. Consumption Impact Effects in the Economy with Collateral Constraints

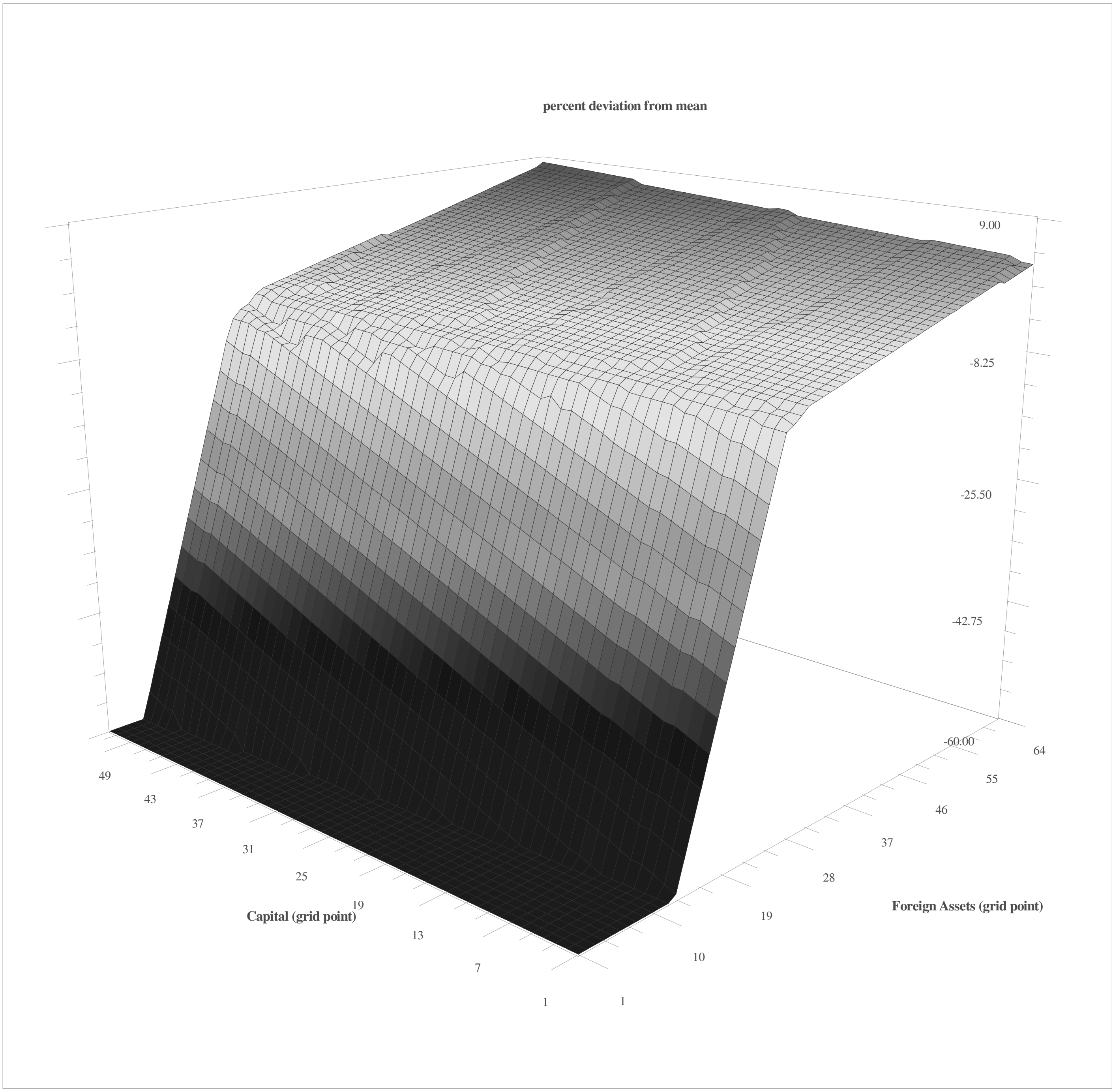


Figure 11. Consumption Impact Effects in the Economy with Perfect Credit Markets

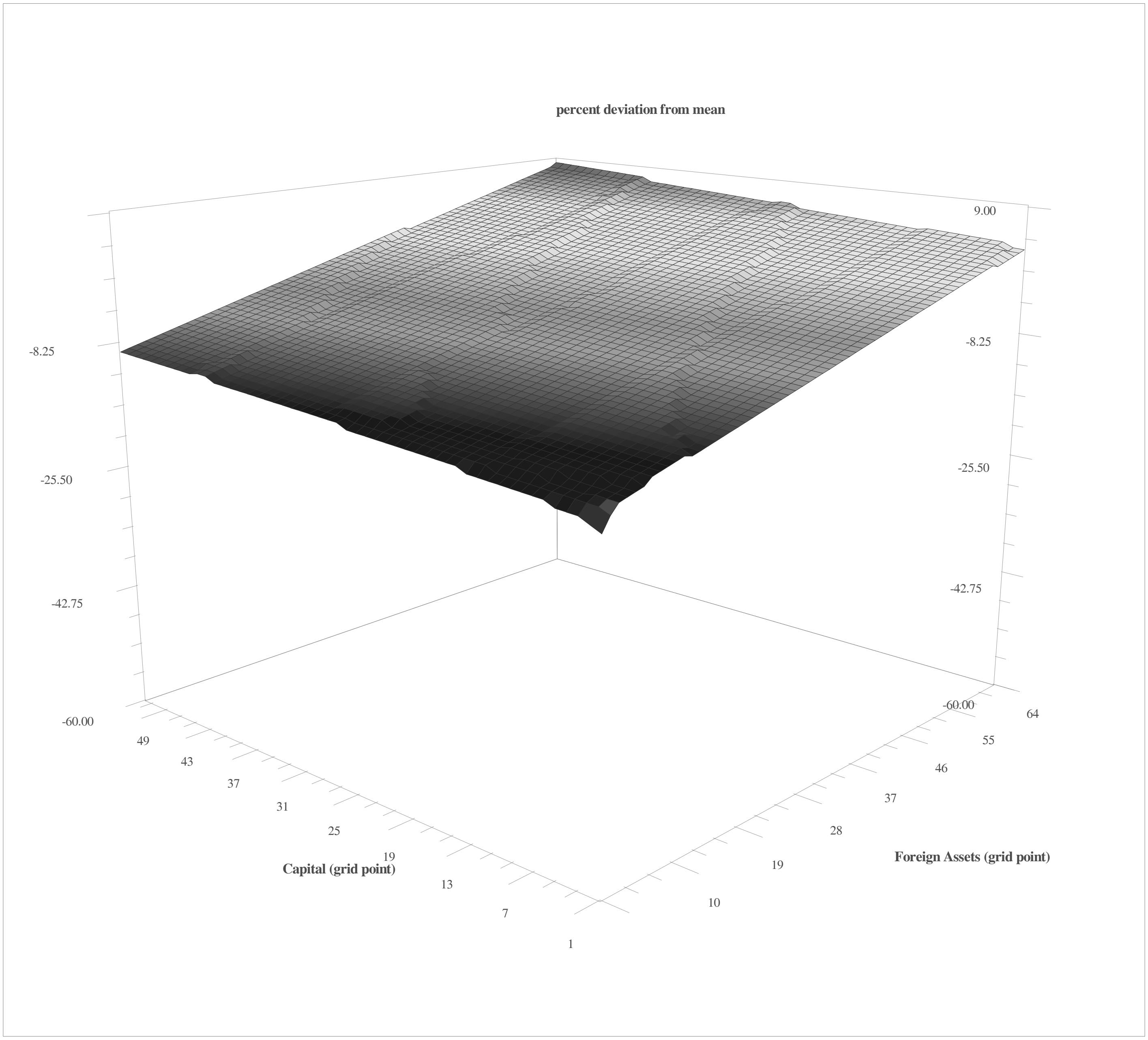


Figure 12. Equity Price Impact Effects in the Economy with Collateral Constraints

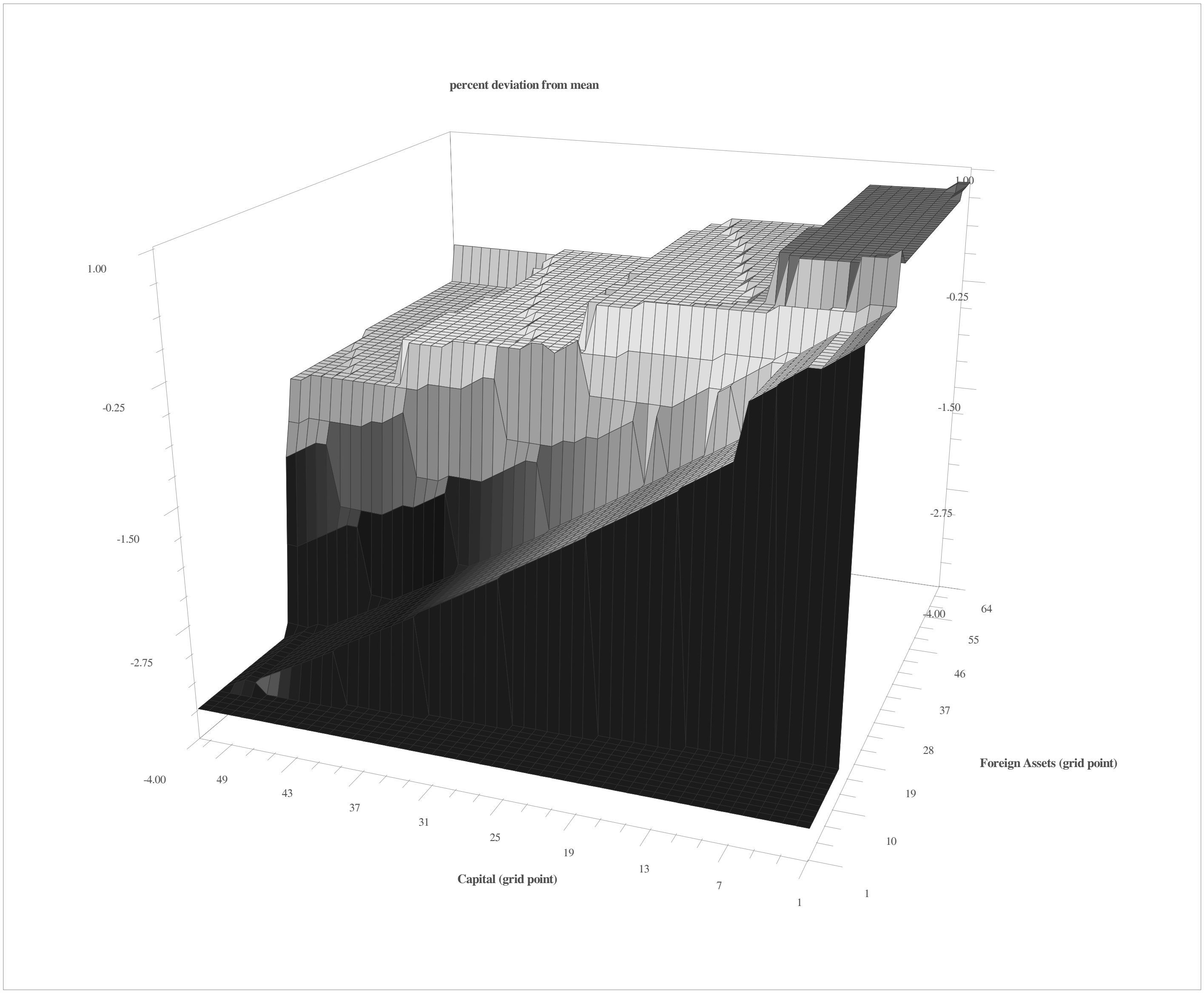


Figure 13. Equity Price Impact Effects in the Economy with Perfect Credit Markets

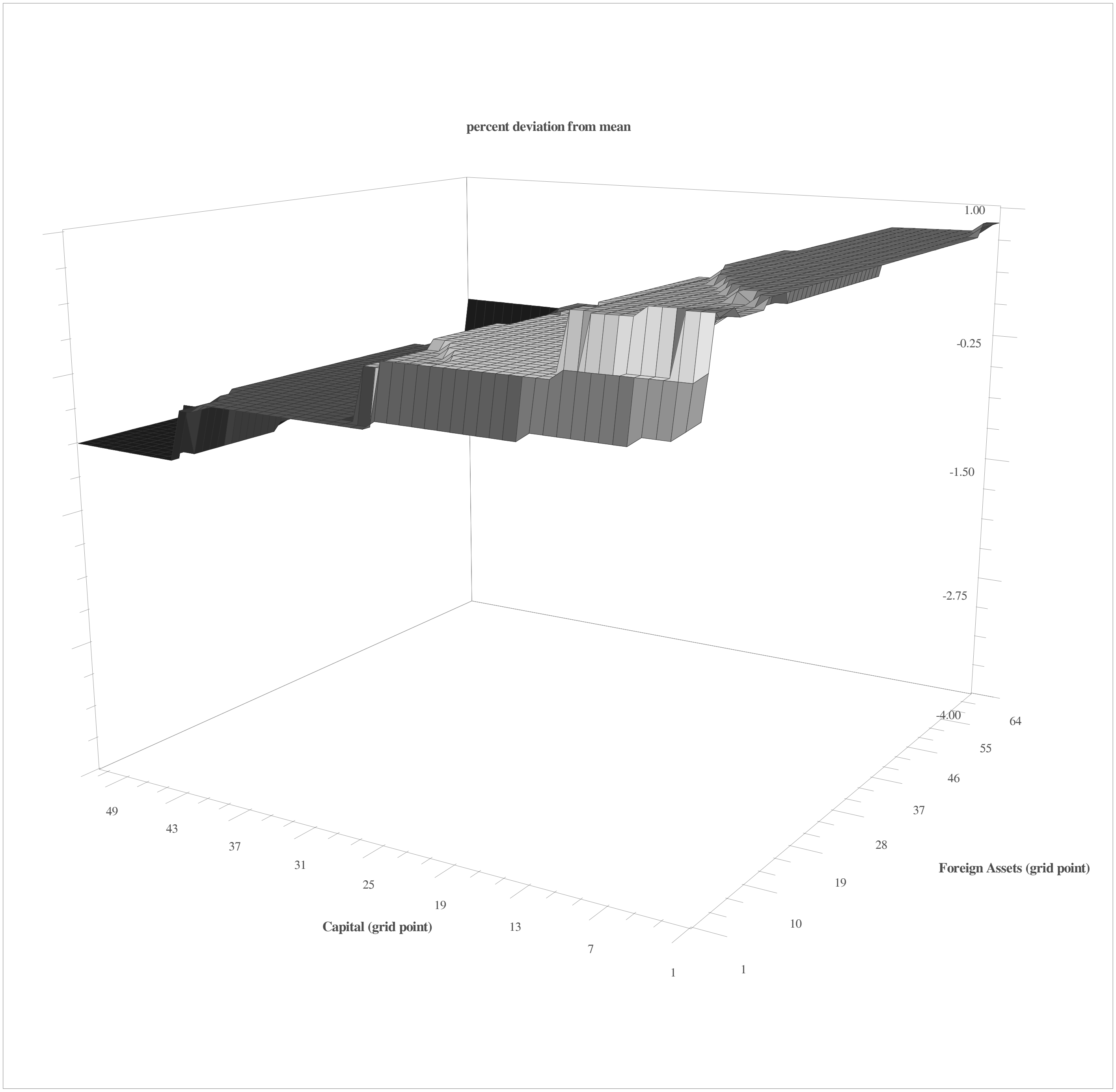


Table 1. Mexico: Business Cycles and the Sudden Stop of 1995

variable	standard deviation	standard dev. relative to GDP	correlation with GDP	first-order autocorrelation	Sudden Stop (date in brackets)	Sudden Stop relative to standard dev.	sample
GDP	2.649	1.000	1.000	0.683	-8.313 (1995:2)	3.138	1980:1-2002:4
private consumption	3.260	1.231	0.891	0.711	-8.685 (1995:3)	2.664	1980:1-2002:4
investment	10.264	3.875	0.959	0.813	-29.991 (1995:3)	2.922	1980:1-2002:4
current account-GDP ratio	2.072	0.782	-0.787	0.732	4.840 (1995:1)	2.336	1980:1-2002:4
equity prices	14.199	5.360	0.574	0.558	-27.679 (1995:1)	1.949	1993:1-2002:4
intermediate goods prices	9.555	3.607	-0.665	0.723	26.883 (1995:1)	2.813	1993:1-2002:4
real world interest rate	1.595	0.489	-0.001	0.276	n.a.	n.a.	1980:1-2002:4

Note: The data were logged and detrended using the Hodrick-Prescott filter with the smoothing parameter set at 1600. The real interest rate is the average 3-month U.S. T-bill rate deflated by U.S. average consumper price inflation. Equity prices and intermediate goods prices correspond to real prices in units of the GDP deflator. Intermediate goods prices are measured using the price index for imported intermediate goods. "Sudden Stop" corresponds to the lowest deviation from trend observed in the corresponding variable (for the current account-GDP ratio it is the largest change in percentage points observed in two consecutive quarters). The GDP correlations are computed for the common sample 1993:1-2002:4.

Table 2. Long-Run Business Cycle Moments in the Simulations of the Baseline Model

variable	mean	standard deviation (in percent)	standard deviation relative to GDP	correlation with GDP	first-order autocorrelation
I. Frictionless Economy					
GDP	33.911	2.687	1.000	1.000	0.661
consumption	22.850	2.332	0.868	0.733	0.847
investment	5.408	10.264	3.820	0.426	-0.037
curren account-GDP ratio	-0.018	1.415	0.527	0.481	0.214
capital stock	49.055	1.595	0.594	0.485	0.724
foreign assets-GDP ratio	-28.596	15.711	5.847	0.075	0.996
equity prices	1.015	0.314	0.117	0.335	-0.062
debt-value of capital ratio	-19.454	10.664	3.968		
intermediate goods	25.461	2.876	1.070	0.960	0.609
capacity utilization	84.129	2.630	0.979	0.794	0.272
working capital	7.998	2.876	1.070	0.201	0.609
working cap.-net sales ratio	23.770	0.239	0.089	0.000	0.234
	Savings-investment correlation		0.600		
	GDP-world interest rate correlation		-0.093		
II. Economy with Collateral Constraint set at 40 percent					
GDP	33.908	2.693	1.000	1.000	0.662
consumption	22.872	2.291	0.851	0.757	0.894
investment	5.407	10.257	3.808	0.432	-0.030
curren account-GDP ratio	-0.018	1.402	0.520	0.468	0.200
capital stock	49.046	1.627	0.604	0.488	0.736
foreign assets-GDP ratio	-27.393	16.805	6.240	0.084	0.995
equity prices	1.015	0.314	0.116	0.339	-0.055
debt-value of capital ratio	-18.639	9.801	3.639		
intermediate goods	25.459	2.882	1.070	0.960	0.611
capacity utilization	84.131	0.263	0.098	0.786	0.274
working capital	7.997	2.882	1.070	0.202	0.611
working cap.-net sales ratio	23.770	0.239	0.089	0.000	0.234
	Savings-investment correlation		0.603		
	GDP-world interest rate correlation		-0.092		
III. Economy with Working Capital Constraint set at 23.532 percent					
GDP	33.718	2.791	1.000	1.000	0.631
consumption	22.725	2.495	0.894	0.753	0.775
investment	5.405	10.304	3.693	0.525	-0.036
curren account-GDP ratio	-0.017	1.425	0.511	0.420	0.217
capital stock	49.025	1.600	0.573	0.489	0.724
foreign assets-GDP ratio	-28.400	15.839	5.676	0.685	0.996
equity prices	1.015	0.315	0.113	0.429	-0.061
debt-value of capital ratio	-19.222	10.693	3.832		
intermediate goods	24.890	4.285	1.535	0.821	0.406
capacity utilization	83.930	0.413	0.148	0.695	0.134
working capital	7.819	4.285	1.535	0.259	0.406
working cap.-net sales ratio	23.531	0.001	0.000	0.000	0.234
	Savings-investment correlation		0.601		
	GDP-world interest rate correlation		-0.286		
IV. Economy with Collateral & Working Capital Constraints					
GDP	33.716	2.796	1.000	1.000	0.633
consumption	22.746	2.456	0.878	0.775	0.766
investment	5.404	10.305	3.685	0.530	-0.029
curren account-GDP ratio	-0.016	1.413	0.505	0.404	0.205
capital stock	49.016	1.632	0.583	0.492	0.735
foreign assets-GDP ratio	-27.269	14.559	5.206	0.773	0.995
equity prices	1.015	0.315	0.113	0.432	-0.053
debt-value of capital ratio	-18.460	9.836	3.517		
intermediate goods	24.888	4.289	1.534	0.821	0.408
capacity utilization	83.931	0.414	0.148	0.691	0.135
working capital	7.818	4.289	1.534	0.260	0.408
working cap.-net sales ratio	23.531	0.001	0.000	0.000	0.234
	Savings-investment correlation		0.603		
	GDP-world interest rate correlation		-0.285		

Note: Standard deviations are in percent of the corresponding mean, except for variables defined originally as ratios.