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Using Signal Processing Tools for Regulation Analysis and Implementation

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M E X I C O

Using Signal Processing Tools for Regulation Analysis and Implementation

The case of the Reserve Requirement rules for the foreign exchange transactions on the Mexican Banking System

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Abstract

Regulators often face the challenge of designing and implementing rules that both, respond to the policy objectives and that can be clearly referred to the day-to-day operations and practices in the marketplace. In many cases, the actual codes end up being a cumbersome collection of conditions that are very difficult to evaluate and re-design. This paper suggests that some of the most commonly used tools in Signal Processing could offer a convenient vehicle for tackling these difficulties. By starting from a **SIMULINK**® model of the regulation of *Banco de Mexico* on the foreign exchange transactions of commercial banks, this papers offers an example of how those tools could be used in this context.

Introduction

Regulators often face the challenge of designing and implementing rules that both, respond to their policy objectives and that can be clearly referred

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[†]First draft. Comments welcome

to the day-to-day operations and practices in the marketplace. In many cases, specially in the areas of taxation, payment systems and regulation of financial intermediaries, the actual codes end up being a cumbersome collection of definitions, conditions, restrictions and cross-references that, *ex post*, are very difficult to evaluate and fine tune.

One way of tackling this problem would be to try to write down every equation implied by the existing regulation in order to get to a closed form solution that could help in assessing its effects. The problem with this approach is that most regulations include various forms of discontinuities and non-linearities that rarely have a closed form solution. An alternative would be to use the structural form to run simulations and from there work through some *optimization method* to improve the rules, *i.e.* by sequentially excluding equations or by recursively calibrating some of the parameters. This approach has the disadvantage of presenting the policy maker with too many parameters to look at, leaving him not very sure about the final outcome of any ulterior regulatory reform.

From this perspective, I believe that the tools that economists commonly use for designing optimal policies offer little relief to practitioners, specially when dealing with regulatory design.

In fact, taking this on a practical stand, one thing is to deal with a abstract maximization exercise where the idea is to find the best path or reaction function for a control variable it; and a very different one, when the government sets specific rules for the way in which individual agents interact among them and with its agencies. In the first situation, one could comfortably rely on dynamic programming techniques, whereas the complexity of the second is more analogous to the design of complex dynamic systems where a series of inputs come together, are added, lagged, or combined to get an output.[1]. In fact, the alluded tools have some noteworthy advantages:

They have been thought for large and complex dynamic systems They are commonly used improving the design of complex devices running from microprocessors to automobiles or aircrafts.

Robust visualization tools Resources such as *periodograms*, *zero-pole* plots, frequency response, system response and impulse response functions,

[1]Notwithstanding, for many commonly used dynamic programming models in Economics, one could find a direct relationship between the Euler equations and Linear Time Invariant Filters. Some examples can be found in Reynoso [12]

offer a set of visualization tools that help to understand the basic construct of a system without an explosive use of parameters.

Well developed computational algorithms There are a large number of algorithms at hand that facilitate the computation and simulation of complex dynamic system, back and forth the time and frequency domains.

This paper uses the Banco de Mexico regulation of foreign exchange transactions of comercial banks as an example of how these tools could be used in the context of financial sector regulation. Section 1 presents the background of such regulation; Section 2 shows the **SIMULINK®** representation of the regulation that will be used as the kernel for all simulations. Section 3 analyzes the regulation looking, first, at its implicit regulatory costs, and then at its dynamic properties in the time and frequency domains. Section 4 explores issue of defining the criteria for improving the regulation and finding an implementable solution.

1 A background on the reserve requirements in foreign exchange in the Mexican Banking System

1.1 The changing role of commercial banks in Mexico's financial crises in the seventies and eighties

Mexico has experienced several external financial crisis over the last 25 years. Even though the financial ramifications of each collapse have hit the banking sector in every instance, the role of the banks as vehicles for the propagation and amplification of the shocks has been different thorugh time [2].

In the mid-seventies, the banking sector was small and overly regulated along the most traditional lines of the financial repression literature [7]. Borrowing and lending rates were fixed by the authorities; banks had to meet lending quotas to specific sectors, and the reserve requirements set

[2]For a good summary see Aspe [1] for an account of the recent crises and Cavazos [4] for a background on the evolution of the Mexican banking sector

by the Central Bank were in fact the preferred instrument to finance the government deficit. Banks were significantly constrained in their operations in foreign exchange, limited basically to currency exchange and payments. In this environment, the 1976 peso devaluation, only had an effect on the banks to the extent that they lost some deposits due to capital flight, however this drain was promptly accommodated by Banco de Mexico. Furthermore, to the extent that both, the government and the commercial banks had few liabilities abroad, the adjustment of the balance of payment disequilibrium proceded along the lines of a current account correction via the depreciation of the real exchange rate and an economic slowdown.

In the early eighties the impact and role of banks was different. They were allowed to take loans from abroad; to take dollar denominated deposits from the public [3], and to make loans in dollars. Borrowing and lending rates were gradually freed and, specialized banks merged into institutions that had a wider range of borrowing and lending activities. However, this first round of liberalization of the industry was not accompanied by any sort prudential rules. On the foreign exchange area, no provision was set to prevent banks from taking large uncovered positions, specially in a context where people could shift their peso deposits into dollar checking accounts on sight. [4].

Resulting from this circumstance, the most noticeable consequence of the series of devaluations occurring throughout 1982, was [5] a partial default via a forced conversion of the dollar deposits into peso deposits at an exchange rate below the market rate [6]. Also, when the government defaulted on its debt, the commercial banks which had accumulated a significant external debt of its own, found themselves incapable of rolling over any of it. Adding to the liquidity crunch, one has to also think of the large exchange losses that had to happen back then. However, their exact size and the mechanism through which they were absorbed is less clear, because banks were taken over by the government with nationalistic overtones, for what became, *de facto*, a comprehensive bailing-out of an insolvent banking sector.

During the rest of the eighties, the balance sheet of the government-owned commercial banks shrunk significantly, therefore limiting its capacity to amplify any shock. The government remained as it primary client, and their

[3] Referred in the literature as *mex-dolares*

[4] This had to do in part with the fact that the official exchange rate policy could not acknowledge an eventual devaluation, for it was based on a fixed exchange rate regime

[5] See Rogers [14], Blanco and Garber [2], Ortiz [10] and Dornbusch and Reynoso [6]

[6] This means less pesos per dollar *vis à vis* using the market rate

range of operations was reduced again by forbidding any dollar transactions with the general public.

In first years of the nineties were marked by Mexico's restored access to the international financial markets. This was true for both, the government and the banks. Also at the time, the government launched and ambitious program to modernize the economy. The privatization of the banking sector was part of this endeavor [7].

As a part of the actions taken to have the banks ready for sale, Mexico's financial authorities took significant steps to change the way in which monetary policy was conducted, as well as to redefine the basic prudential regulation for these institutions. On the monetary policy side, Banco de Mexico moved away from a reserve-requirement-based framework for the management of monetary aggregates (and for funding the deficits), and decided to rely solely on open market operations [8]. On the credit side, the basic Basle-type standards became the backbone of the prudential regulation established by the Ministry of Finance.

Banks were allowed to carry out operations in foreign exchange with other intermediaries at home and abroad and with corporations inside the country, with no further limitation than the ones implied by the capitalization rules. Taking deposits from the public and lending to them in foreign exchange, remained off limits.

1.2 The propagation of the 1994-1995 crisis through the banking system

Mexico's 1994 crisis is marked by the sudden suspension of re-financing flows for both, the public and the private sector. The consequences of this situation hit the banking sector to an extent that sent it to bankruptcy for the second time in 20 years, at a price tag that exceeded US80bn, almost 15% of GDP.

There is a consensus among analysts that the holes in the prudential regulation, compounded by a loose enforcement, brought about unexpected complications in the handling of the already serious macroeconomic situation

[7] See Teichman [16] and Rogozinski [15] for a more general discussion on privatization in Mexico, and Ortiz [9] and Haluk and Navarro [17] on the specifics of bank privatization

[8] The annual reports of Banco de Mexico during the period 1991-94 have a very thorough and interesting description of how these operational changes came about

during the first quarter of 1995. *Ex-post*, the banks and the government found out that the former had failed to hedge a sizeable foreign exchange exposure and had most of their liabilities maturing in a few days.

The full propagation of the crisis through the financial industry took several months, with changing characteristics as time went by.

The first symptom was a liquidity crush. Right after the authorities announced the first so called *"small devaluation"* in December of 1994, the international markets reacted casting serious doubts about the capacity of the government to repay short-term dollar-indexed peso-bonds [9], which in turn lead to a sudden stop in capital flows into Mexico. At the time, the commercial banks had most of their liabilities in the form of interbank credit lines and *callable-structured loans* [10].When the flows of financing from abroad stopped, not only banks found themselves unable to roll-over their credit lines, but needed additional funding to repay the contingent obligations, already deep in the money.

From Banco de Mexico's point of view, this was nothing but a run on the Mexican banks with the caveat that it was not being performed by domestic depositors but by banks from abroad. In contrast to what happened back in 1982, the authorities decided to avoid defaulting to the largest possible extent. Under these circumstances, it was clear that the Central Bank could not rely on simply extending their peso credit lines; therefore the run was ultimately taking place on its own foreign exchange reserves.

After realizing that the government soon had to roll over close to 35 billion US $, plus another 9 billion US $ from the banking sector, the *mini-devaluation* became a *maxi-devaluation*, when Banco de Mexico had no other choice but leaving the foreign exchange market in order to keep its scant reserves to stand behind these liquidity needs.

With respect to the needs of the banks, the Central Bank implemented a dollar denominated last-resort credit facility to support those in distress. At some point, as much as 3,800 US $ [11] were drawn through this special purpose window.

[9] Known as *Tesobonos*

[10] Contingent liabilities which typically included clauses that made them callable depending of the price of an underlying security

[11] See Banco de Mexico's Annual report for 1995 [5], page 82

Then came the exchange rate losses. It is fair to say that some pre-existing regulation put in place by the Central Bank in 1992 mitigated the size of the losses [12] stemming from the drop in the exchange rate. Banks were required them to limit long or short positions in foreign exchange to 5% of their statutory basic capital. It was later realized that this rule had the shortcoming of not including in the definition of a short position the contingent component of the alluded *structured-loans*. As a result, when the circumstances made those liabilities callable, and the time came to mark them to market, substantial losses became evident, hitting this time the solvency of the banking institutions. The problem took a while to show up in their balance sheets, but when it did, it was not only sizeable but generalized.

Finally; came the avalanche of bad loans. Whereas the first two stages took place fairly sooon, the last part of the collapse of the banking sector happened along several months, as the Mexican economy shrank at a pace unseen since the Great Depression. Thousands of loans became non-performing, eating up the capital and forcing a large scale rescue operation.

1.3 Policy response

In Mexico, the Central Bank and the Ministry of Finance regulate and supervise banks concurrently, although each one specializes in some areas. Banco de Mexico oversees matters related to the payments system, such as clearing in the securities and interbank credit markets; and transactions in foreign exchange. In turn, the Ministry of Finance, through its Securities and Exchange Commission, issues and enforces the rules related to capital adequacy and accounting principles. This paper paper focuses on the directives issued by Banco de Mexico, and therefore on the policy response to what happened in the first stage of the $1994-95 banking crisis$. For further reading on the policy response to the exchange and loan portfolio loses of the banking sector, a list of references can be found in Reynoso [11].

For regulators in Banco de Mexico , the 1994 crisis underscored the fact that their responsibility with respect to the payments system, was to be

[12] Regulatory letter 2/92

able to always ensure *the convertibility*[13] of the instruments that enter their definition of monetary aggregates across them and across currencies.

Right when the authorities had to make a number of important changes in the operational framework for conducting monetary policy, and when they were about to pick an exchange rate regime,[14], it was already clear to them that guaranteeing a successful *convertibility* required to substantially improve the capacity of banks to meet their funding needs in foreign exchange under conditions of stress.

It also became clear that the discussion about regulating the foreign exchange transactions, and the modalities of the foreign exchange rate regime were two sides of the same issue. That is , if the banking system was weak and institutions were rationed in their access to funding in dollars, the Central Bank will have to play the role of lender of last resort in the hard currency anyway. Therefore, even if the local currency was allowed to float *freely*, Banco de Mexico would have to hold international reserves to support institutions in distress when needed. Hence, whether they wanted or not, it was very likely that central bank interventions in the foreign exchange market would take place in a way similar to what one would see in a *dirty floating*: that is, dollars would be supplied into the market by the Central Bank in times of financial stress.

Once all this was realized, regulators needed to set the guidelines for handling the risk of *a bank run* in foreign exchange. Here they had basically two alternatives:

Deal with credit needs in dollars in the same way as in pesos . After all, if money was fungible and all markets are interconnected, there should be no reason for making a distinction between the operations in either currency. In this case, the Central Bank would need to determine an adequate level of international reserves as well as some rules for granting and charging for the loans when used.

Establish a sort of exchange controls on banking transactions. This is, looking for a way in which the reserves of liquidity in foreign exchange could be built at the level of each individual bank.

[13] Understanding this word in the sense of the previous paragraph and not as a synonym for a Currency Board.

[14] See Carstens and Gil Diaz [3] as well as the 1994 and 1995 annual reports of Banco de Mexico

In deciding which one of the two approaches to follow, the authorities were making an implicit assessment on the situation of the commercial banking system.

For instance, it could be argued that the model of a permanent dollar discount window, would badly serve its purpose in a context of weak banks. This is because they would have substantial incentives to take large risks, like betting on the appreciation of the real exchange rate and the drop in interest rates, to meet their large accrued and/or undergoing losses. A solution like this would further transfer the downside costs to the Central Bank. This would also imply subsidizing the worst banks at the expense of those with a higher commitment with risk management.

Now, although the second model had the advantage of transferring the cost to each individual bank, it was likely to limit the access to genuine business opportunities by the better banking institutions. Also, there was the challenge of setting rules that were progressive (*i.e.*that would impose a heavier burden on riskier institutions; simple and enforceable. In addition, in this case, like with managing any other regulation based on quotas, the authorities would also have to cope with numerous forms of elusion and evasion. This, would also open the door to discretionarily responses of regulators to exceptions and market innovation.

After this debate, the authorities opted for the second approach by issuing the regulatory letter known as 2019/95. The next sections pursue its description and analysis.

2 A description of the reserve requirement rules using SIMULINK®

So far we have taken a look at the problem and at the objectives that the Central Bank wanted to achieve. We are yet to see how the authorities executed their intended plan.

The regulatory circular 2019/95 issued by Banco de Mexico[15], through its section M.1, subsections M.13 and M17 [16]; section M.5, subsections M.51

[15]The full text of this circular is available on the Internet at the following address: http://www.banxico.org.mx/dDisposiciones/FSDisposiciones.html. Also, a well commented description of this regulation can be found in Hernandez [8]

[16]These sections have to do with general definitions of assets, and liabilities; rules for compensation of assets and liabilities and the corresponding reporting rules

and M.52 [17]; and section M.6, subsections M.61 and M.63 [18], implements the mechanism that Central Bank regulators thought was the most fit to address the risk of *runs* in foreign exchange.

As it happens with most regulatory directives, the 2019/95 has plenty of cross-references and a number of constraints between variables defined from other variables, making it a somewhat dense piece to analyze. Hence, from a methodological standpoint, the challenge consists of trying to develop a structured framework to effectively evaluate what the government is actually doing.

At this point, we will start using tools specifically developed for designing and understanding relatively large and complex dynamic systems, like SIMULINK®, and its Digital Signal Processing Module.

2.1 Notation

This section describes the content of the relevant sections of the 2019/95 directive in terms of difference equations and a number of constraints. Conceptually, one could think of the set of rules as a filter that transforms some input signals, in this case, funding and lending in foreign exchange by commercial banks; into their observed *dollar book*.

The representation of this rules borrows the notation widely used in the *Signal Processing* literature, in terms of signals and blocks.

Figure 1 lists the blocks used in this paper. They have been grouped in three categories.

The sources , In general, they are thought as sequences of independently distributed random variables.

The operators , corresponding to the usual definitions of "Delay n", as the lag operator for n periods; "Gain", equivalent to scaling the signal by a given factor; "Integrator", it being the operator that shows the cumulative sum of the value of the signal at each moment; "Sum", the arithmetic sum or substraction of the value of two or more signals at each node; the "Minmax" operator, is the which sets constraints of the kind $max[\ ]$ or $min[\ ]$; and "Mux" (for multiplexing) and "Demux"

[17]Regarding derivatives and other contingent claims
[18]Dealing with foreign exchange uncovered positions

(for de-multiplexing) operators which facilitate the grouping and un-grouping of signals in the implementation of the model.

The output sinks , that either send the resulting signal from one sub-system to another; "Out n", or portray the final output in the time and/or in the frequency domains; "Scope".

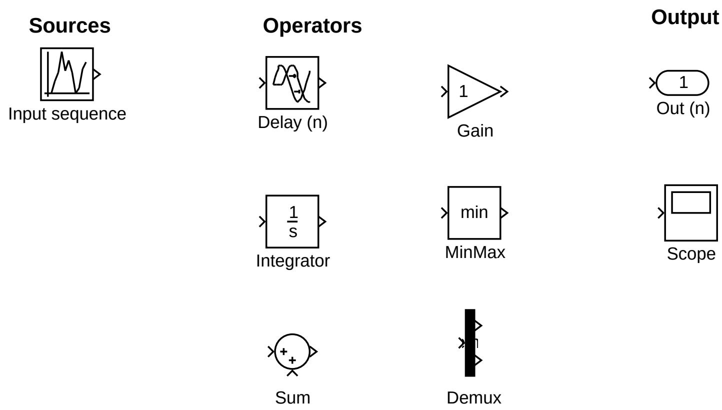

Figure 1: Building blocks

2.2 The SIMULINK® model

Figure 2 is a system which has two built-in sub-systems. Looking first at the larger picture, one could see thatthe starting point chosen by regulators was to classify assets and liabilities by maturity and by quality. Then, they would try to match both sides of the balance sheet by both criteria. To achieve this goal, they introduced 5 definitions whose precise meaning follows from inspecting Figure 2:

Net Position Difference between total assets in foreign exchange minus total liabilities in foreign exchange.

RAL [19] This a weighted average of the foreign exchange liabilities. The weighing factors are inversely proportional to their time to maturity.

[19]Acronym for Required Liquid Assets.

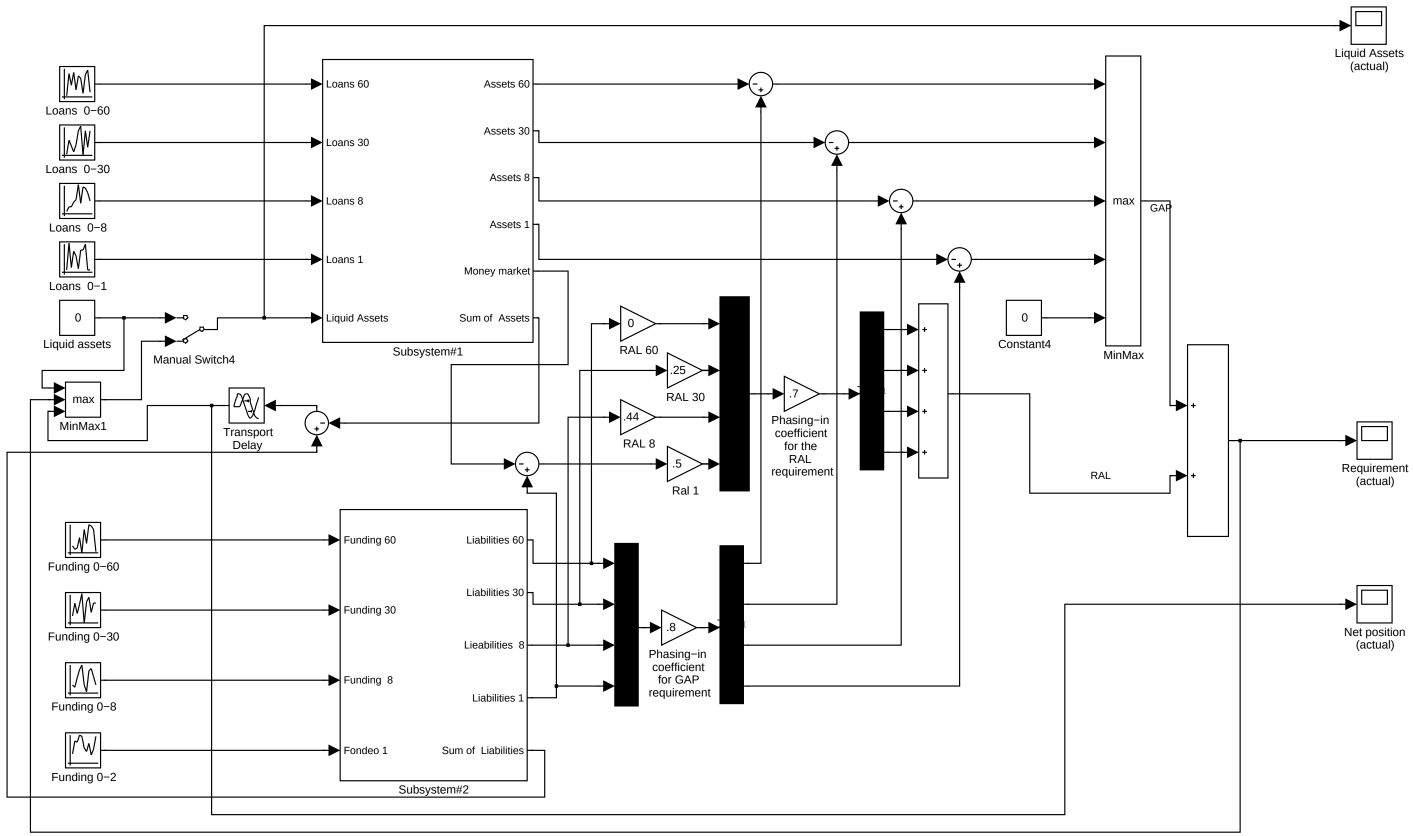

Figure 2: Structure of Regulation#2019/95

GAP The maximum of the differences between assets and liabilities ordered by maturity class.

Phasing-in coefficient Since banks could not meet the standards set by the rules at the outset, regulators mitigated its impact by applying some "phasing-in" coefficients to the GAP and RAL definitions.

Reserve requirement Corresponds to the output signal in Figure 2.

Sub-system #1 in figure 3 shows the way in which the regulation classifies assets by maturity date. The rules see three types of assets. First, the lending portfolio in foreign exchange, then the so called *Money market assets*; which are all kinds of tradeable securities denominated in foreign exchange, and finally, the *liquid assets*, being them deposits in top rated banking institutions incorporated in a G7 country and short term US Treasury issues. All assets are classified by their maturity dates and then used to determine the GAP, RAL and position numbers.

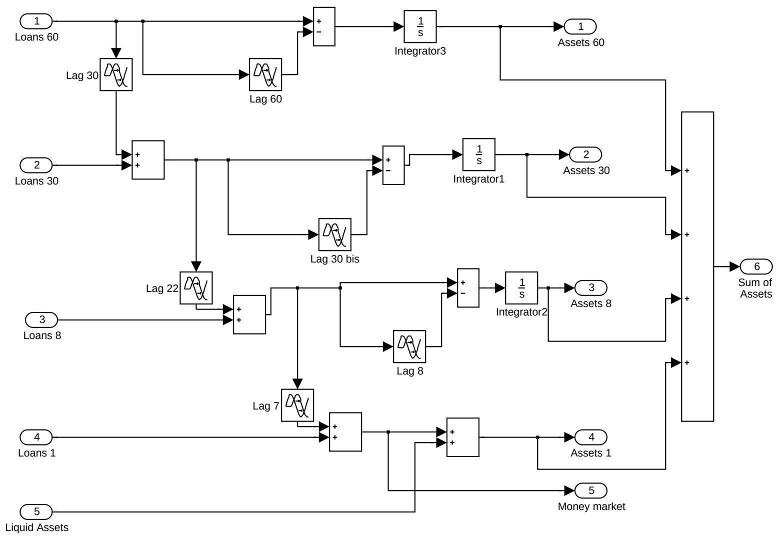

Figure 3: Assets under Regulation 2019/95

Sub-system #2 in figure 4 shows the dynamics of liabilities implied by the rules. In contrast with the way in which assets are treated, there is no distinction in terms of quality. However, the rule tries to make sure that all contingent liabilities are somehow marked to market. [20]

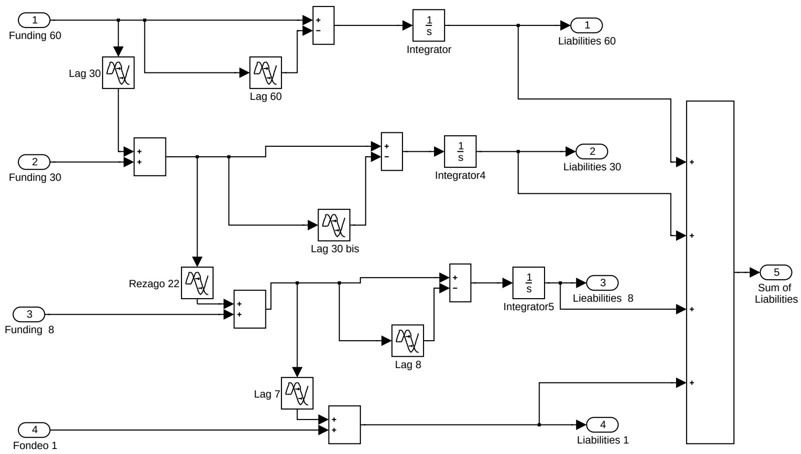

Figure 4: Liabilities under Regulation 2019/95

Now, several years into the operation of this regulation both, regulators and banks have tended to agree that the 2019/95 had somehow contributed to reduce the vulnerability of banking institutions to the volatile funding environment that most *emerging economies* had been facing. However, there has also been the sentiment that these rules tend to exaggerate the level of required reserves [21] and to amplify the day-to-day fluctuations in the foreign exchange market.

In the next section we will try to assess to what extent this *sentiment* can be substantiated. By experimenting with the system of figure 2, we will try to visualize the implications of its design.

3 Analyzing the properties of rule 2019/95

In understanding a regulation like this, one could benefit from experimenting with the system. That is, by comparing various input sequences

[20] It is beyond the reach of this document to discuss how this is done, however it should be mentioned that there are so many varieties of contingent contracts written between intermediaries, some of them rather complex, that the authorities have had their share of surprises when finding some *ex-post* unanticipated losses in intermediaries who were thought to be marking to market properly.

[21] From here onwards, we will use the term *reserves* and *liquid assets* interchangeably

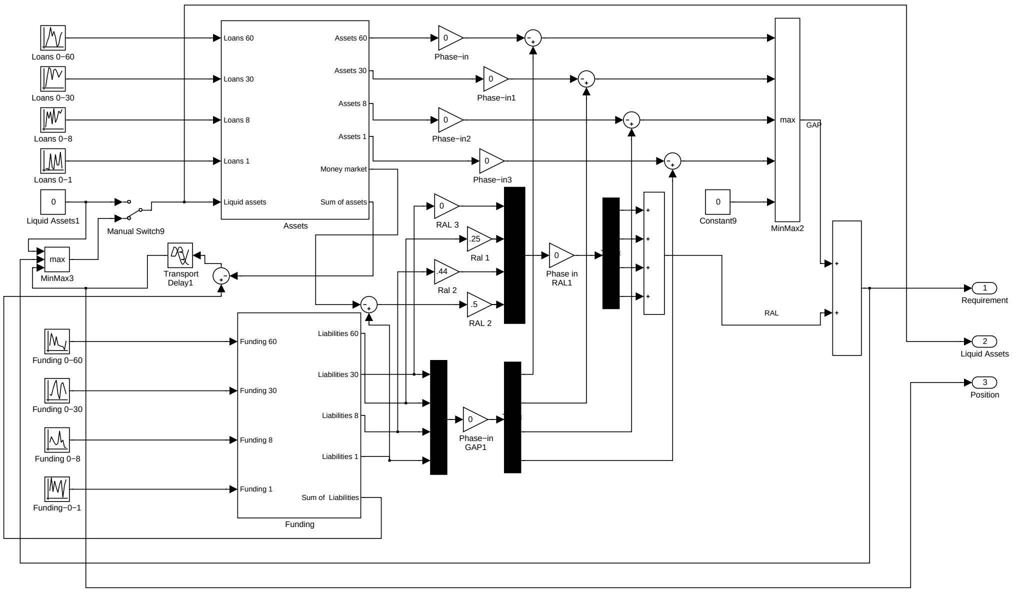

Figure 5: Base Case System

and its respective outputs, one could make inferences about its properties as a filter. Therefore, the task for this section is:

- First, to define a base case scenario, this will be the one with no regulation; and an alternative scenario, which captures the effects of the regulation.
- Second, define a set of simulations. Each simulation will input data from different generating processes, with the purpose of highlighting the properties of the *system* from diverse and complementary angles.
- Third, use the comparison between the base case and current system to design an improved filter.

For reference throughout this document, we will think of the *current* model as the one in figure 2; whereas the system structure for the *un-regulated* scenario is shown in figure 5.

As for the simulation parameters for both models such as lag orders and gain factors, we will keep the ones that appear on each of the respective graphs, except for the properties of the input series which will be modified along the lines hinted above. Finally, the algorithm used for running these simulations will be the Dormand-Prince with fixed-steps in round.[22]

3.1 First set of simulations: assessing the cost to banks

The purpose of the first round of simulations is to get an idea of how costly this regulation is to the banks. To that end we specify the input data generating processes for $loans_n^l$ and $funding_n^f$, as independent draws from

$$max[0, N \sim (0, \sigma)] \tag{1}$$

for all l and f, where n is the simulation step; $l = \{1, 8, 30, 60\}$ is the index for the term structure of loans, and $f = \{1, 8, 30, 60\}$ the respective index for the finding variable. The burden of this regulation is defined by the difference

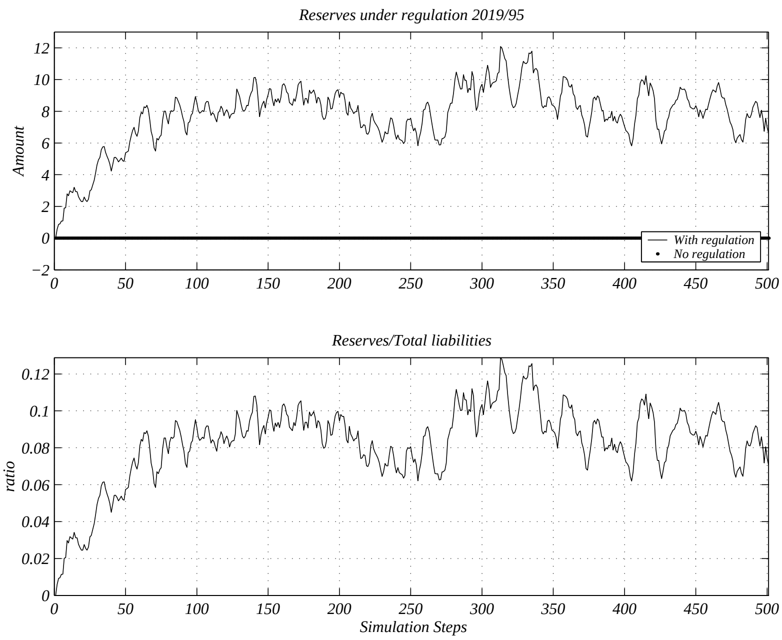

Figure 6: Simulated Reserves (Liquid Assets)

between the funding costs and the return that banks get on their liquid investments in high quality paper and deposits in top rated institutions.

[22]For further detail see the technical documentation of SIMULINK®

Given the fact that it has not been unusual to see the funding [23] of Mexican banks priced at least one hundred basis points above the United Mexican States (UMS) sovereign issues, in this section we will take spread over US Treasuries to be around 500 basis points.

Figure 6 presents the simulated levels of liquid reserves for the normalized case where $\sigma = 1$ for 500 steps. At glance, the rule induces a significant holdings in low yield assets.

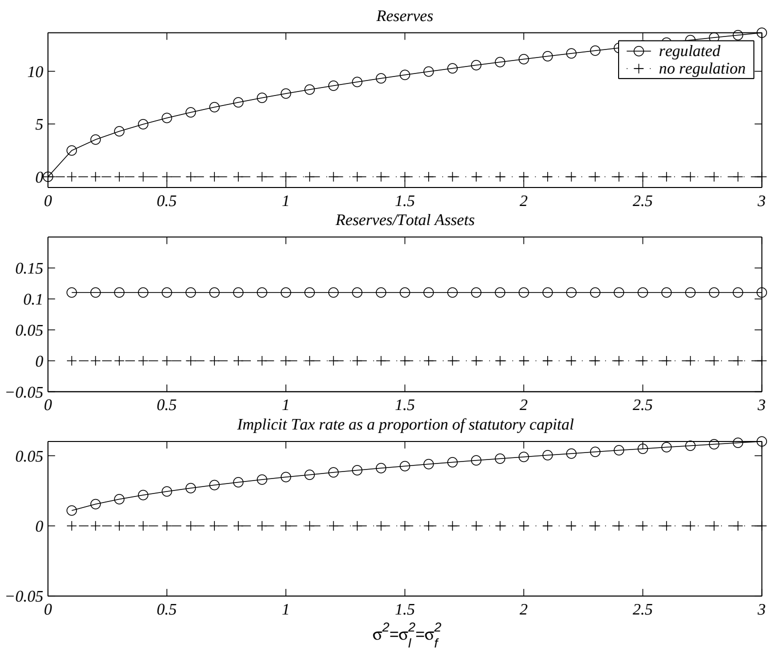

Figure 7: Mean Level of Reserves and Position under different scenarios of underlying volatility

Here, one could mention that for relatively extended periods between devaluations, holding a long position *vis-a-vis* Mexican assets has represented relatively high costs to those who have them. This due to the process of real appreciation of the exchange rate between the crises, as well as resulting from the effect of high real interest rates in pesos, typical of the *post* and *pre-devaluation* times. In spite of that, and resulting from the fact that, *ex-post*, a long position covers the devaluation risk, we will omit the carry of such long position in the computation of the cost to banks. Notwithstanding,

[23]Non-securitized or non-collaterallized interbank loans

this variable will be revisited in section 3.3, in the context of the impact of the regulation on the foreign exchange market.

Figure 7 shows the comparison between the average level of *liquid assets* in the free and regulated cases, for different values of the standard deviation $\sigma = \sigma_l = \sigma_f$, 2.

Figure 7 shows the tax implicit in regulation 2019/95, expressed as a proportion of the statutory capital of the banking system [24]. The plots display its value as a function of the underlying variance of the fundamental input signals [25]. The first panel contains the average level of reserves resulting from the simulations. The cost is defined by expression 2 :

$$C = \frac{Reserves}{Total\ Assets} \frac{Total\ Assets}{Statutory\ \ Capital} \ 500\ bp \tag{2}$$

The first fraction on display in the second panel of figure 2; the second one is set to $\frac{1}{.08}$, and the last component is the assumed cost of carrying these reserves. The numbers that come out of this simulation, when seen in terms of a reasonable rate of return on the capital behind the dollar books of a banking institution, is far from negligible. In fact, it could range anywhere between 15%to 25% of a reasonable gross rate of return.

3.2 Second set of simulations: performance under stress

The next question to address is on the form in which this regulation covers the *risk of a run*. To that end the input signals of figure 2 are specified as step processes with the values shown in table 1:

Input signals	$n \geq 1$	$n \geq 8$	$n \geq 30$	$n \geq 60$
funding				
$f = 1$	1	1	1	1
$f = 8$	0	1	1	1
$f = 30$	0	0	1	1
$f = 60$	0	0	0	1
loans				
$l = 1, 8, 30, 60$	0	0	0	0

Table 1: Parameters for the input step sequences

[24]Tier 1 capital set at 8% of total assets

[25]Each kind of assets and liabilities in figure 2 is defined as a fundamental input signal

The results are shown in figure 8. The light line in the upper panel corresponds to the amount of required liquid assets by the regulation, whereas the heavy line shows the outstanding level of liabilities at each point in time. The lower panel displays the ratio of liquid assets to total liabilities.

Two facts can be highlighted. First, the regulation covers a large proportion of all liabilities with a maturity of 60 days or less with low-yield *riskless* assets. Second, the proportional coverage is not very different for 8, 30 and 60 day maturity liabilities. The latter implies that the rule imposes essentially the same burden to banks with relatively different maturity profiles. It also points at the notion that the rule may be unnecessarily complicated if its compared to an alternative one which simply would state to hold a certain proportion of all 60 day or less liabilities.

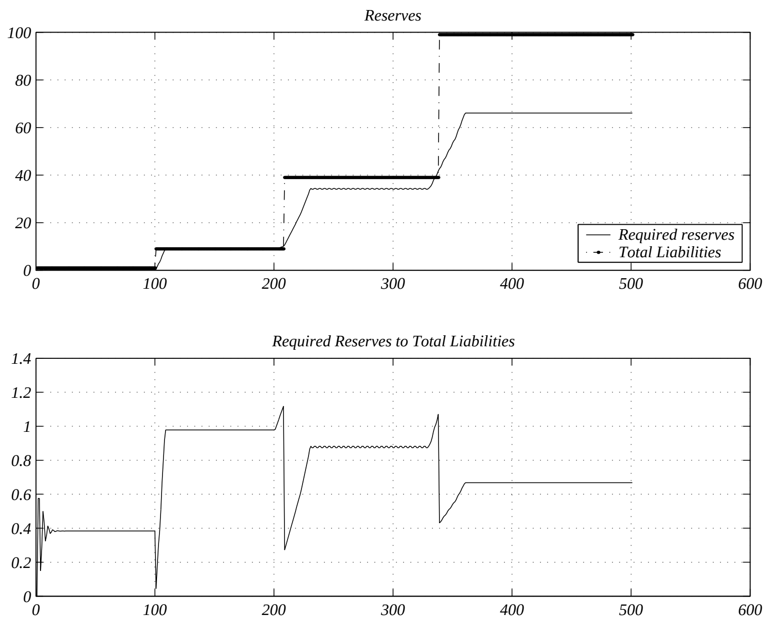

Figure 8: Coverage of Liabilities by Reserves

3.3 Third set of simulations: looking at the dynamic properties of the rule

3.3.1 Notation for a Fourier Analysis

It can be shown that for the parameters and structure of the system in figure 2, the *box* that connects the input and output signal behaves like a Linear Time Invariant (LTI) filter [26]. What will makes a Fourier representation of this LTI filter useful is that the convolution operation implied by the system, is mapped to multiplication. In addition, the Fourier transform for discrete time signals will provide us with an insightful way to interpret the system.

For notational purposes lets define the sequence $y(n)$ to be the output series, $x(n)$ to be the input series and $h(n)$ the unit *impulse-response* sequence of the system, for $-\infty < n < \infty$. Lets also define the discrete-time Fourier Transform(DTFT) of any sequence $v(n)$ as:

$$\begin{aligned} V(e^{j\omega}) &= \sum_{n=-\infty}^{\infty} v(n)e^{-jn\omega} \\ j &= 2\pi i \\ i^2 &= -1 \end{aligned}$$

In general, $Z(e^{j\omega})$ is *complex valued* and depends on the frequency ω of the complex exponential. Thus, it can be written in terms of its real and imaginary parts or in terms of its magnitude, $|Z(e^{j\omega}|$; and phase, $\phi_h(\omega)$: [27]

[26] This means that if all inputs are multiplied by a scalar, the output will also be multiplied by the same scalar. Also, if the input series is shifted (to the right or left), the output series is also shifted in the same phase and direction. Another way to say this is that when a signal is passed through a LTI filter, it shows only a change in complex amplitude with no change in phase

[27] The Fourier transform is known to allow to recover the original series $v(n)$ by :

$$v(n) = \frac{1}{2\pi}\int_{-\pi}^{\pi} V(e^{jw})e^{jnw}d\omega$$

$$
\begin{aligned}
V(e^{j\omega}) &= |V(e^{j\omega}|e^{j\phi_h}(\omega) \\
|V(e^{j\omega}|^2 &= V(e^{j\omega})V^*(e^{j\omega}) \\
\phi_v(\omega) &= tan^{-1}\frac{V_I(e^{j\omega})}{V_R(e^{j\omega})}
\end{aligned}
$$

The analysis in the following paragraphs is built on the fact that the Fourier transform of the *unit impulse-response* sequence can be obtained from the Fourier series of the input and output sequences. Starting from the definition of convolution,

$$
\begin{aligned}
y(n) &= h(n) * x(n) \\
&= \sum_{k=-\infty}^{\infty} h(k)x(n-k)
\end{aligned}
$$

and applying the Fourier transform on both sides of the equation,

$$
\begin{aligned}
Y(e^{j\omega}) &= \sum_{n=-\infty}^{\infty} [\sum_{k=-\infty}^{\infty} h(k)x(n-k)]e^{-jn\omega} \\
&= \sum_{k=-\infty}^{\infty} h(k)[\sum_{n=-\infty}^{\infty} x(n-k)e^{-jn\omega}] \\
Y(e^{j\omega}) &= \sum_{k=-\infty}^{\infty} h(k)X(e^{j\omega})e^{-jk\omega} \\
&= X(e^{j\omega}) \sum_{k=-\infty}^{\infty} h(k)e^{-jk\omega}
\end{aligned}
$$

we can see that the Fourier transform of the output series is the product of the Fourier transforms of the input series and that of the *impulse response.*

$$
Y(e^{j\omega}) = X(e^{j\omega})H(e^{j\omega})
$$

Also, from the fact that the *Power Spectra* (*phase*) of the regulation could be obtained from the ratio (differences) of the *Power Spectra* (*phases*) of the input and output sequences, as seen from expressions (3) and (4)

$$|Y(e^{j\omega}|^2 = |X(e^{j\omega}|^2|H(e^{j\omega}|^2 \quad (3)$$

$$\phi_y(\omega) = \phi_x(\omega) + \phi_h(\omega) \quad (4)$$

3.3.2 The simulation results

Figure 9 shows the simulation results of the reserve requirements in foreign exchange for a data generating processes which considers draws from a $N \sim$ (0,1) for all l and f. The upper panel displays the sequence for the case where regulation 2019/95 is present. The lower panel is the base case scenario.

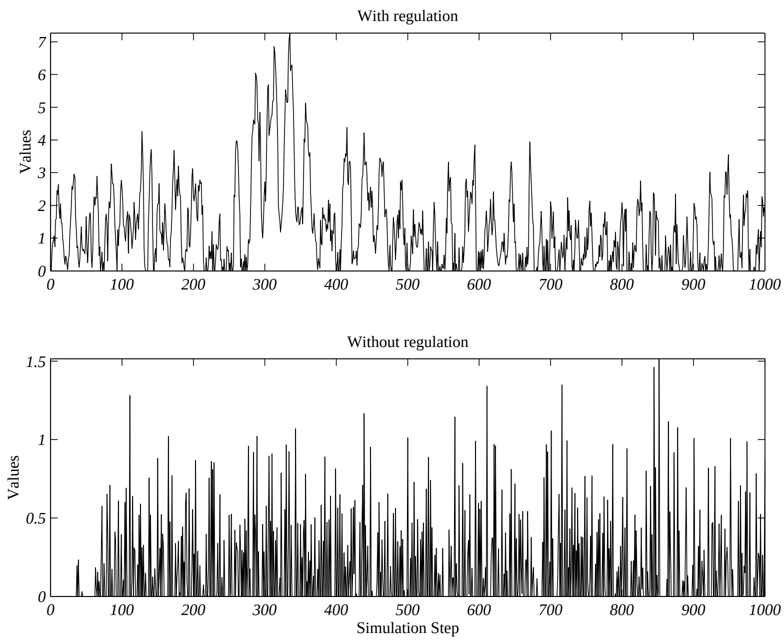

Figure 9: Reserves in foreign exchange

In tirn, figure 10 has the input and output signals for the dollar *net position*, where a positive number stands for a long position in dollars. As we suggested in section 3.1, the regulation induces the intermediaries to hold in average, larger long positions. Also, both, the reserves and the net position variables seem to show more amplitude and persistence in the scenario with the regulation present. These features can be perceived more clearly if we transport these sequences to the frequency domain.

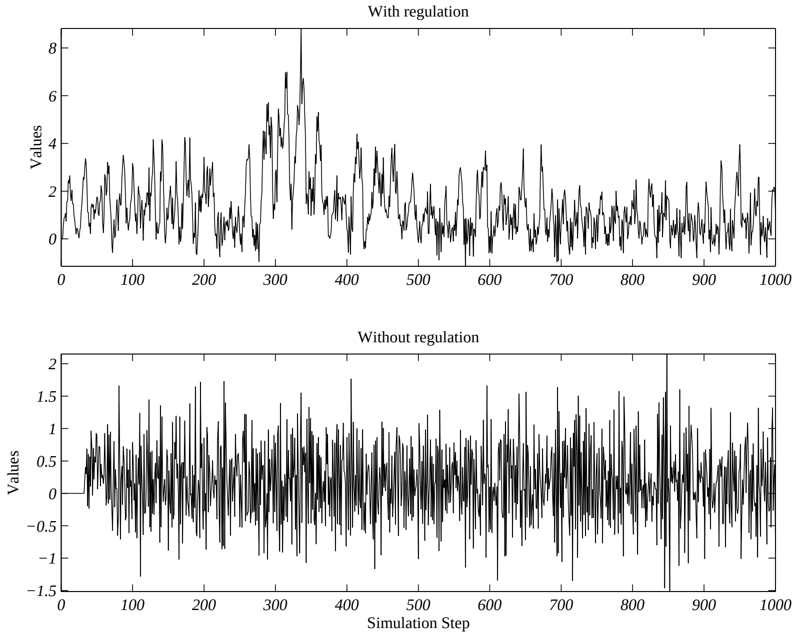

Figure 10: Net position in foreign exchange

3.3.3 The *frequency response* sequence

Figure 11 shows the *power spectrum* of the input and output series of dollar reserves. For convenience, the x axis is presented in cycles per day. Hence, the closer a value is to the origin, the lower the frequency of the periodical component.

The inspection of the two *spectra* confirms what has been said all along: on the one hand, regulation 2019/95 tends to introduce significant persistence, particularly in the components with 5 days to 1 month persistence. Secondly, it amplifies both, the low and high frequency harmonics.

Figure 12 has the *frequency response* of the regulation on the *net forex position*. The pattern is essentially the same as the one shown by the *reserves* variable: the appearance of low frequency harmonics and the amplification of the high frequency waves.

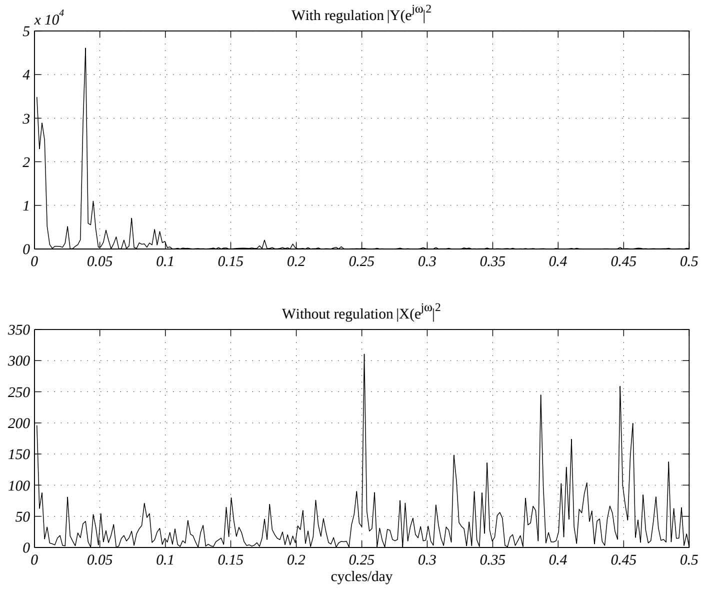

Figure 11: Power Spectrum for Reserves

It is true that latter may look like a necessary evil: after all the 2019/95 rule aims at having banks to build up their own reserves in foreign exchange in face of short term funding shocks. However, it can also be seen as a negative side effect of the rule. In fact, one has to bear in mind that the net position of banks can also be seen as their net demand in the foreign exchange market. Having a participant in this market with such a *regulation-induced* demand could hardly contribute to a more stable price of the currency in *normal* times. We will come back to this topic in the next section.

A useful way of representing the above information is given by figures 13 and 14. They have the ratios of the *power spectra* of the output and input series. According to equation (3), these ratios are equivalent to the square of the magnitude of the *frequency response* of the filter that transforms the input signal into the output signal.

This magnitude is the *gain* that the filter applies to each of the harmonics that compose the input series. Here we see again how the structure of the rule not only amplifies short term shocks, but also adds magnitude and persistence to the shocks that affect the *net position* , which in turn would be likely to add low frequency waves into the dynamics of the exchange rate.

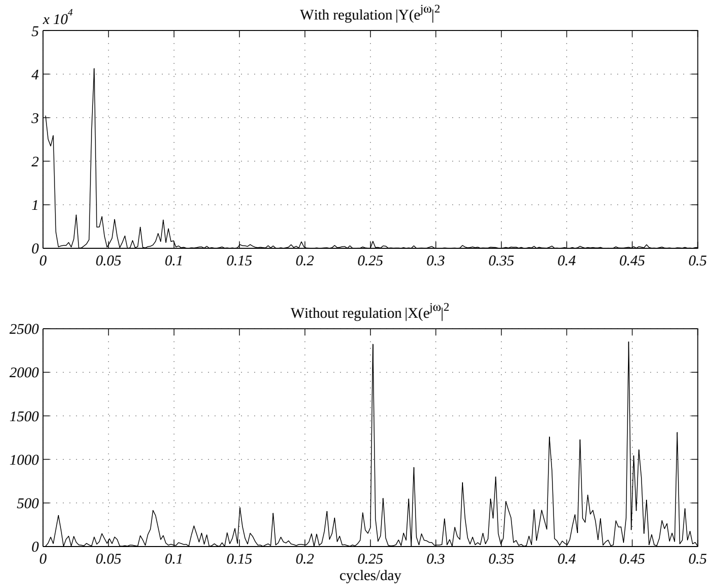

Figure 12: Power Spectrum for Position

3.3.4 The impulse-response function

The relationship between a Fourier transform and a z-transform allows one to take yet another look at the time domain properties of a filter like regulation 2019/95.

For notation purposes, lets see expression (5) as the z-transform of the previously defined sequence $v(n)$

$$V(z) = \sum_{n=-\infty}^{\infty} v(n) z^{-n} \tag{5}$$

From inspection it follows that $V(z)$ is the discrete time Fourier transform of the sequence $r^n v(n)$. Conversely, the z-transform of $v(n)$, evaluated on the unit circle $z = 1$ corresponds to its Fourier transform.

Now, take $h(n)$ to be the unit sample response of the system, and $H(z)$ to be its z - transform, referred onwards as the *system function.* Lets say that we find a way to represent $H(z)$ as the rational function (6):

$$H(z) = A \; \frac{\prod_{k=1}^{q}(1 - \beta_k z^{-1})}{\prod_{k=1}^{p}(1 - \alpha_k z^{-1})} \tag{6}$$

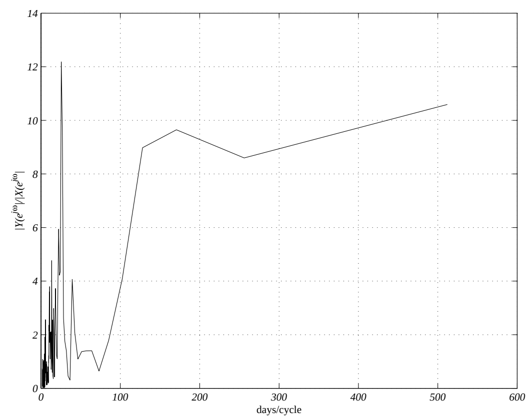

Figure 13: Magnitude of the *frequency response* for Reserves

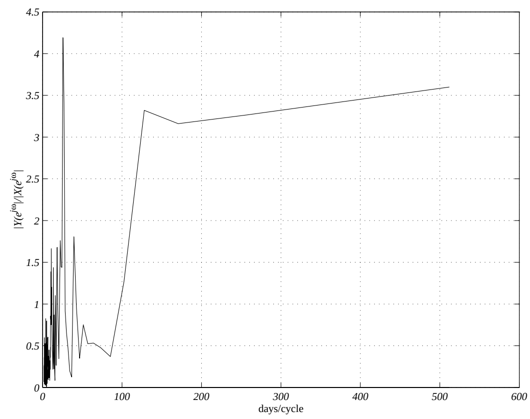

Figure 14: Magnitude of the *frequency response* for Net Position

One could then rewrite (6) as:

$$H(z) = \frac{\sum_{k=1}^{q} b_k z^{-k}}{\sum_{k=1}^{p} 1 + \alpha_k z^{-k}}$$

which is known to be the z transform of a linear constant coefficient difference equation of the following form :

$$y(n) + \sum_{k=1}^{p} a(k) y(n-k) = \sum_{k=0}^{q} b(k) x(n-k) \tag{7}$$

where $x(n)$ and $y(n)$ are the input and output signals respectively.

The roots of the numerator polynomial in equation (6), β_k are referred as the zeros of $H(z)$ and the roots of the denominator polynomial,α_k as the poles. To the extent that the β and α provide a concise representation of the *system function* up to a constant, the *zero-pole* plot can be a useful tool for analysis. Conventionally, the poles are represented as "x" and the zeros as "o".[28]

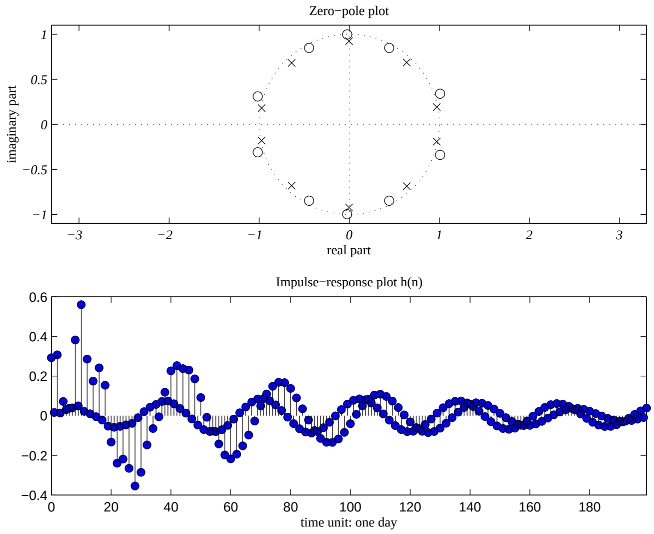

Figure 15: Unit impulse response for Reserves

The upper panel of Figure 15 displays *the zero-pole* plot for the filter that transforms the *reserves* signal. The lower panel is the impulse response polynomial $h(n)$. Focusing on the *zero-pole* results, it is worth mentioning that:

- All poles lie inside the unit circle, meaning that the system is *stable* and *causal*.
- The complex poles and zeros occur in complex conjugate pairs resulting from the fact that $h(n)$ is real valued.

[28]The region of convergence (ROC) for the z-transform is, in general, an annulus of the form $\alpha <| z |< \beta$. If $\alpha = 0$, the ROC may also include the point z=0; if $\beta = \infty$, then the ROC may also include infinity

- Most zeros and poles are very close to the unit circle, which is typical of *minimum phase* systems. This implies that the *frequency response* of the system can be described only in terms of its *magnitude* $|H(e^{j\omega})|$.

- Looking at the plot in a counterclockwise direction we confirm what we already know. Deriving from the fact that he first pole on the unit circle is closer to the horizontal axis than the first zero. we know that the system has a component that has a bigger *spectral power* at very high frequencies. Also, to the extent that the second pair of a zero and a pole on the unit circle shows the same order, and given that the separation between the two of them is similar, the filter shows a larger *power spectrum* at lower frequencies.

Taking a look now at the *impulse-response* plot, again we see two cyclical components arising, one with the larger amplitude with a period of about 40 days, and a second with a period of more or less 30 days. Furthermore, transitory shocks show some impact even after 180 days.

Finally, we end this section by looking at figure 16 with the *zero-pole* plot and impulse response of the rule for the *net position* variable. Although the results are very similar to the ones in figure 15:

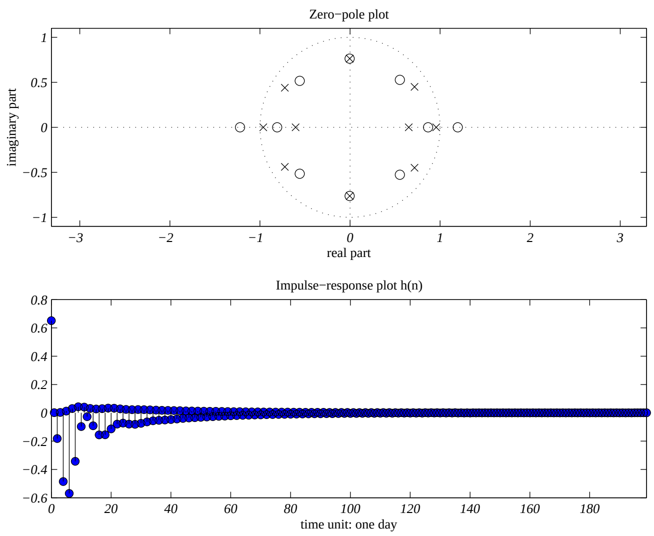

Figure 16: Unit impulse response for Position

- The *zero-pole* plot shows a pair of zeros and poles on the horizontal axes that appear in conjugate reciprocal pairs. This is characteristic of an *allpass* filter.

- Moving again in the counterclockwise direction, wee see the zero farther away in terms of an angular distance than the pole. This translates into a higher *spectral power* for smaller frequencies. Now, from the fact that the zero and pole located in the middle of the *arc* formed by the unit circle and each quadrant, are more to the center of such *arc* than in figure 15, we could think that the power contribution of the filter at lower frequencies is somewhat more moderated in the case of the *net position* variable, than in the case of *reserves*.

4 Improving the filter design: *patching* the regulation

Although we are hardly at a point where we could generalize any observation on the way the risk management policy of the Mexican authorities works, one could not avoid noticing that in the effort to avoid a large but sporadic bad event, the anti-crisis measures implicit in rule 2019/95, introduce some features which are not necessarily the most desirable. The previous section highlighted some of them:

- It is costly, hoovering around 4% of the statutoru capital of commercial banks.

- It shows a poor correlation between the required reserves and the average maturity of loans in the 1-60 day range.

- Makes transitory shocks larger and more persistent.

4.1 Why not doing it all over again?

Between a complete overhaul and doing nothing, there is a wide spectrum of minor changes that can be done. In fact, it is very likely that the authorities would like to try first some small changes before travelling the road of re-engineering. There may be some good reasons for that:

The high political cost of un-doing. Implementing and enforcing a regulation as cumbersome as this one required a good deal of negotiations between the Central Bank and its commercial counterparts. Eliminating or replacing the existing rules by others entirely new could mean re-starting the whole process of lobbying and explaining, at the risk of ending up with something worse than what is there today.

Lack of clarity. Not having very clear how far the regulation goes and what are its precise macro and micro effects would also make the authorities hesitant on what parts of it need to be changed or adjusted.

Administrative costs of changing the rules. Every new rule means changes to reporting and accounting systems within the banks and at the Central Bank. It also entails the training of supervisors, compliance officers and operators. Taking a sharp turn in the basic philosophy of the rules could bring about very high transition costs without having the certainty that the new rules will work better than the older ones.

Easier to undo. Last, but not least, when changes are small, they can be undone at a lower political and operational cost.

Now, assuming that there may be a greater temptation on the side of the parties involved to build upon the current rules rather that changing them altogether, the practical question would be how to adapt, or *patch* them in a way that effectively addresses its current shortcomings.

4.2 Desirable characteristics for a *patch*

Without trying to exclude any other features that the policy maker may find desirable, one could think of the following:

Preserve the capacity to cover the *"risk"*. Namely, one would be looking for a rule that keeps much of the capacity of the banks to face a sudden stop in the availability of funding from abroad, whereas trying to include features that more closely reflect the relationship between cost and risk. For example, it follows from section 3.2, that rule 2019/92 would *tax* almost the same a bank with much of its liabilities maturing in 8 days and bank with their liabilities maturing in 60 days.

Minimize side effects. The amplitude and persistence of the low frequency harmonics brought about by the regulation seem to generate a potential interference with other elements of the monetary policy, namely in the foreign exchange rate front. A good characteristic of the regulation would be for it to work well in times of stress and to create as little as possible cost during better times.

The signal processing approach offers a rather standard methodology for designing *patches*. Namely, if the policy maker is not in a condition to modify the filter that transforms the input signal in any substantial way, the idea would be to attach another LTI filter at the exit of the existing one in order to get a newer and improved output signal. In the *time domain notation* , this would be to define an *impulse-response* polynomial that would be *convolved* with the current output signal.

The practical, yet not necessarily substantive, advantages of this approach are that the regulator would only need to add one paragraph to the regulation that would instruct bankers and supervisors to keep calculating the same formula, and once they are done, to substitute to the result in a rather parsimonious difference equation.

4.3 Designing and implementing *the patch*

With the aforementioned criteria in mind, one could think of adding a filter to the system that eliminates must of the low frequency harmonics, and keeps some and most of the mid-range and high frequency ones. Intuitively, this approach could simultaneously address both the two points of concern highlighted in section 4.2. That is, by making the burden of the rule more progressive (*i.e.* A lower weight is given to funding shocks that may have an effect later into the future), one would reduce the persistence seen in the currently regulated environment. To implement this idea we proceed along the following steps:

Getting a Normalized Filter The next figures show one simple LTI filter that would eliminate all high-gain and low-frequency spikes of the older filter for *reserves*; to abate the gain in the mid frequency range and to keep the high frequency properties of the regulation intact.

The parameters of the *patch* are set to get an ipulse-response polynomial of order 60 built using an *Equirriple* normalized multi-band method with an *ideal* weight of 0 percent for periods of less than two weeks, 50 percent up to one month; of 70 percent for periods between one and 2 months and 100 percent beyond that. Notice that this design says nothing about the *phase* of the *frequency response* for the *patch*, and that does not consider any feedback between the existing and the older filter. The reason is that the current filter is causal, stable and with minimal phase, as it was shown in section 3.3.4.

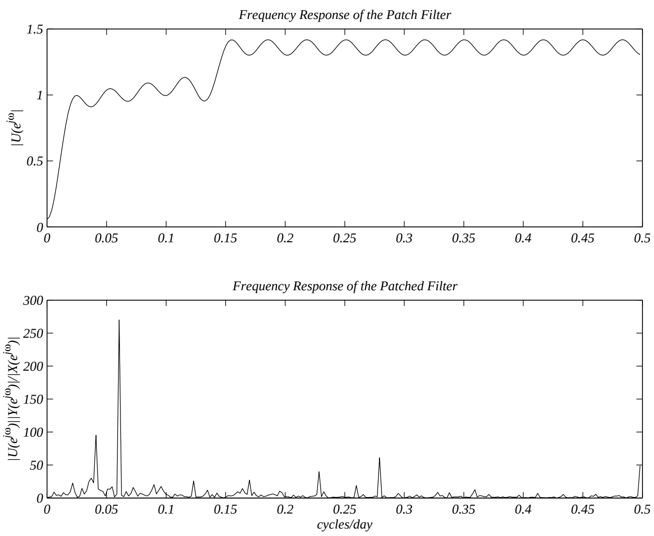

Figure 17: *Patched Filter* Design

Restoring the Power Since the elimination of the low, and some of the mid-range frequency harmonics also takes some of the *power* of the original output series, it would be reasonable to scale up the magnitude of the *frequency response* of the *patch* by a factor that makes the area under the *power spectrum* equal for both, the original and *patched* outcome signal. The upper panel displays the *realizable patch* filter once the adjustment is made ($U(e^{j\omega})$) .[29] The lower panel shows the magnitude of the resulting *frequency response* , $|U(e^{j\omega}||Y(e^{j\omega})|/|X(e^{j\omega})|$.

The *impulse-response* of the *patch* Now, we will just repeat what was done in section 3.3.4; namely, starting from the *frequency response* function; then, obtaining the z-transform and, from there deriving the

[29] We mean that a filter is *realizable* if it is stable and causal.

corresponding impulse response function. As we know, the latter is just the polynomial of weights in a *distributed lag filter* applied to the output signal coming from the current regulation. Figure 18 displays the coefficients $b(k)$ in equation 7. In this case $a(k) = 0$ for all k .

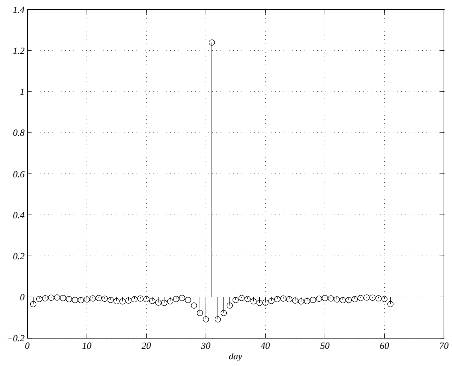

Figure 18: Unit impulse response for the *Patch*

Simulating the *patched* outcome Figure 19 shows a resulting signal for liquid assets and the net position after applying the patch.The data generating process behind this simulation exercise is the same used in section 3.2.

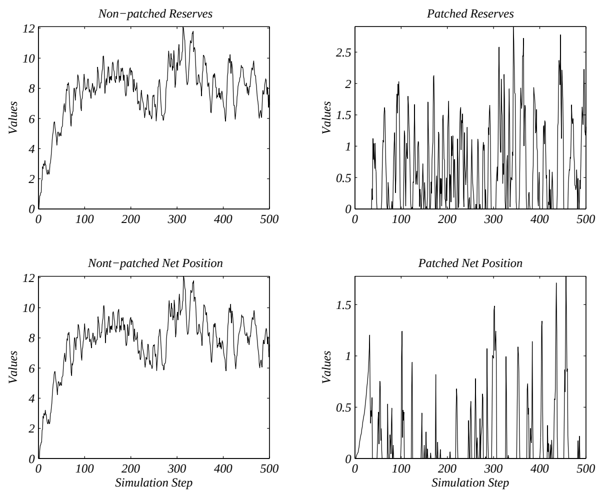

Figure 19: Input and output signals

For comparison purposes, the panels in the left correspond to the original output signals. The modified rule adds, as it was expected, less amplitude and persistence.

Coverage of the *patched* regulation One interesting way of seeing what this patch does is to look at the coverage of liabilities by liquid assets, in the same fashion as we did in figure 8.

This time, as can be seen in figure 20, the patched series shows a very similar level of coverage for short term shocks, and a clearly decreasing coverage as we move to longer term liabilities.

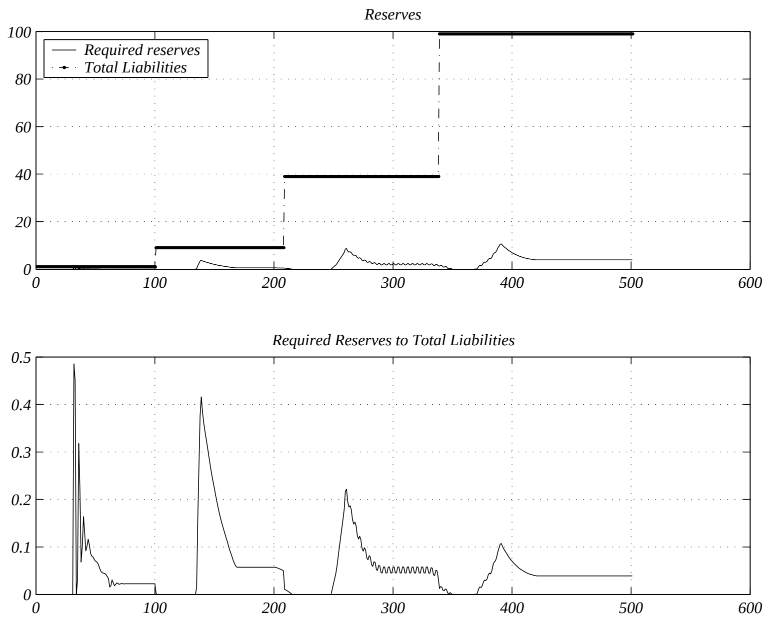

Figure 20: Patched Coverage of Liabilities by Reserves

An interesting twist to this result is that it is very likely that we would have reached the same outcome by adjusting some of the parameters in figure 2, for example the gain coefficients before the **RAL***Mux*. However, it is my impression that the full dynamic consequences of doing that were less obvious, and involved more parameters than the approach followed here. Notwithstanding, one could benefit from going back and forth the calibration of parameters in the system and the design of patch, until finding the solution that is easier to implement.

Concluding remarks

This document talks about two things. On the one hand, there is the methodological issue about using Signal Processing tools for regulation analysis and implementation. On the other hand, at least it raises the question of why regulations, like the one used here as an example, are implemented.

With respect to the methodological considerations, perhaps one could say that as rules get more complicated, it is useful to have some sort of diverse and well known tools, like the *spectrum*, the *impulse response* function and the *zero-pole* plots to evaluate and adjust rules, when the purpose of the policy maker is to make some *minor* adjustments. Maybe the example is not beyond the reach of conventional tools, but thinking of tax laws or some rules for the operation of the payment systems, could make these tools more attractive and useful.

Beyond that, there are more fundamental issues need discussion. Namely, why authorities like the Mexican find necessary to segment the peso and dollar markets in the way they do it. Furthermore, why treat the *convertibility* risk any different than the traditional risk of facing a bank run. Therefore, why not having in place an *incentive compatible* deposit insurance mechanism, very much like the one in operation for balances in local currency. Or, why not reducing the lender of last resort responsibilities of Banco de Mexico by allowing branches of foreign banks to operate [30]in the Mexican market. [31]

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[30]This is not done under the current laws

[31]See Reynoso [13], for further remarks on this topic

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