

Case study: Scenario and Risk Analysis in the Pulp Industry using System Dynamics and Monte Carlo Simulation

Erico Resende Santos <erico.santos@gmail.com>, Gustavo Galli <gustavogalli@suzano.com.br>, Taly Nahmias <talynahmias@suzano.com.br>, Rodrigo Sienra <rsienra@suzano.com.br>, Julianne Archipavas <juliannea@suzano.com.br>

Abstract

Similarly to those of other commodities, pulp prices are highly volatile. In such a capital intensive industry, with high operational risk, proper assessment of future possible scenarios for pulp prices is fundamental for investors' financial and strategic planning. Building excessive capacity can be dramatically harmful for the entire industry. This paper describes a case study where a system dynamics model and flight simulator were used to generate expected scenarios for pulp prices as a tool to support investment decisions. More specifically, a Monte Carlo simulation running on top of the SD model provides a range of expected values for prices in different time horizons with pre-defined confidence levels. Even though the model and specific results cannot be fully disclosed, the paper describes a methodology and techniques which can be applied in several similar problems involving risk analysis and system dynamics applications.

1. Introduction

During the global crisis that started in 2008, the pulp industry saw the international prices of pulp plummet more than 30% in a few months. The price had reached record high levels just before the crisis started. A similar situation had happened back in 2001 (see Figure 1).

Figure 1. Softwood pulp nominal prices in US dollars per tonne (1998 to 2013)



source: (Index Mundi, 2013)

The volatility in prices is harmful for the industry. A high fraction of the costs are fixed which leads to high operational risk. The production is also capital intensive. Plants demand a huge initial investment and the decision to expand is subject to long delays (up to as many as seven years) as the plant is built and the forests developed for raw material. One can reckon the dramatic financial impact of a plant being launched on a period of depressed prices after years of intensive drainage of capital. For that reason it is vital that investors estimate likely scenarios for prices in the future in order to assess risk and make informed decisions.

Prices depend on the production costs and on the balance between supply and demand. The drops seen in Figure 1 are associated to crises that caused shocks on the demand.

The supply can also have a determinant effect on prices. When excessive capacity goes into operation the prices typically fall and, on the other hand, they start to escalate when the supply fails to keep pace with demand. It is therefore crucial to understand the dynamics of supply, demand and costs in order to understand how prices are determined.

All those variables are interconnected. Changes in demand will affect prices, which will affect supply and prices again recursively and all these dynamics will feedback to demand, with varied strength and delay. Because of the complexity involved, System Dynamics can be a powerful methodology to model the problem.

This paper describes the development and use of a System Dynamics model and flight simulator by "Suzano Pulp and Paper", a Brazilian producer, to assist on its investment decisions and strategic planning. The model was built in iterative steps during a period of about 18 months, becoming increasingly complex. The resulting model allows the user to test for several scenarios of demand (with variations in economic growth and use intensity in different regions), costs, supply, exchange rates (which can change the supply chain's regional configuration) among others.

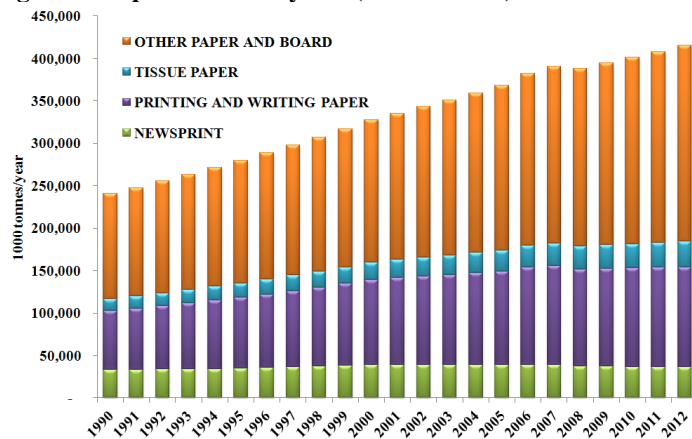
As a final exercise on risk assessment, a Monte Carlo simulation is used on top of the model in order to test for several possible scenarios and to derive an expected range of prices at each point in time in the future with an arbitrary level of confidence. The result of this simulation is regarded by the client as a powerful tool for risk analysis.

The paper is organized as follows: section 2 presents a background of the industry and the client; section 3 discusses the model structure and simulator interface. Section 4 describes the simulations and results. Section 5 presents the conclusions.

2. Background

Cellulose pulp is the basic raw material for paper production. Worldwide paper consumption has been growing steadily, except for the global crisis in 2008. Figure 2 shows that, with the exception of Newsprint paper, all types have grown since 1990. Paper for Printing & Writing seems to have stabilized after the digital revolution and growing concerns with sustainability, mostly in the developed countries. The biggest use is for packaging (reported as "other paper and board") and it is the application with the highest growth in volume. Packaging paper demand is highly correlated with economic activity.

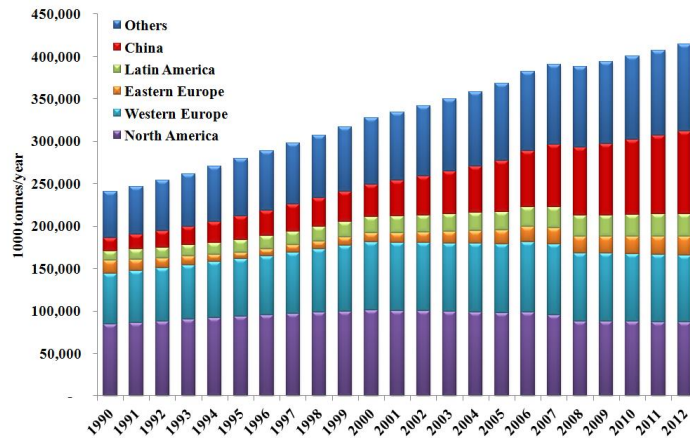
Figure 2. Paper demand by use (1990 to 2012)



Source: Company data

Demand data by region (Figure 3) shows that recent growth is all attributable to developing countries, especially China.

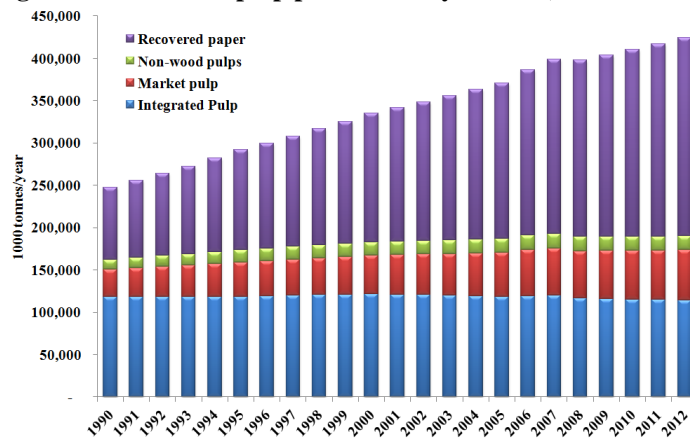
Figure 3. Paper demand by region (1990 to 2012)



Source: Company data

Paper production may use different types of pulp from several sources. Figure 4 shows the evolution of pulp production by source. Recovered paper is by far the source of pulp with the highest growth rate.

Figure 4. Worldwide pulp production by source (1990 to 2012)



Source: Company data

For the problem at hand we are interested in market pulp, that is, pulp produced from wood that is not integrated into the paper production process. Market pulp is a group of commodities traded among pulp and paper producers with an international price set by the market. The chart in Figure 1 shows the international price for one type of market pulp (softwood). Market pulp represents a steady share of the pulp market (close to 14%) and, because the total volume is growing, so is the volume of market pulp.

There are several types of market pulp depending on the raw materials used (mainly Hardwood and Softwood) and the production process (Mechanical and Chemical). The majority can be classified as BSKP (Bleached Softwood Kraft Pulp) and BHKP (Bleached Hardwood Kraft Pulp). Softwood is more predominant in North America and Europe, produced mainly out of pinus wood, while Hardwood is more common (and growing) in Brazil and Asia out of eucalyptus and acacia trees, among other types.

Hardwood pulp has a considerably lower cost to produce both due to productivity and shorter growth rotation of forests. Because of this cost difference, production capacity is

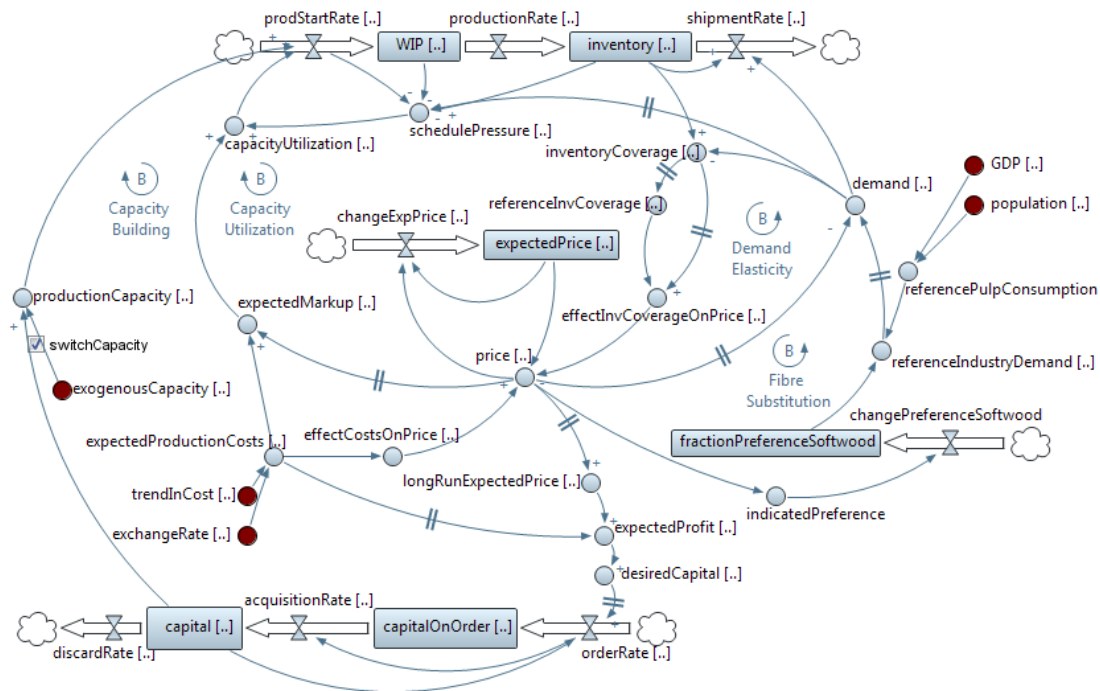
expected to grow mostly in the hardwood producing regions. Some applications must use softwood pulp exclusively, but in many cases there is some degree of substitutability. Because hardwood is cheaper, there is a tendency for the demand to shift from softwood to hardwood following the trend on the supply side.

Suzano Pulp & Paper is the second largest producer of eucalyptus pulp in the world and leader in the paper market in Latin America, selling pulp in 31 countries, the printing and writing (coated and uncoated) paper industry, and the paperboard industry, with four lines and around 30 brands sold in 60 countries. Suzano has 5 plants in Brazil and is expanding with another mill to greatly increase its capacity in hardwood pulp.

3. The Model and Flight Simulator

The model's main purpose is to generate scenarios for the pulp price. The core of the model is similar to a generic commodities model found in Sterman (2000, page 798). A simplified hybrid diagram is shown in Figure 5. The diagram shows the main stocks, flows and other variables, the main feedback loops and the key exogenous variables (shaded circles).

Figure 5. Simplified Diagram



The diagram shows almost all variables as arrays because the model is actually disaggregated into the two main products: Softwood and Hardwood. On the capacity sector the model is also disaggregated into regions, each with its own capacity, costs, exchange rates etc. So the variable "capital", for instance, is actually a two dimensional array. The GDP, population and reference pulp consumption are disaggregated into regions, but not products.

Price is in the centre of the model. It depends on a memory of the past price (expectedPrice) and on the inventory coverage and costs. Prices follow costs and vary in the opposite direction of the inventory coverage. The price memory adjusts to the actual price with a delay (this and other time constants in the model are all parameters that can be manipulated within the simulator interface).

Costs are mostly exogenous, defined for each product and region as a linear trend for the cost in the local currency unit times the exchange rate (all the currency values in the model are expressed in dollars deflated to 2012). Subsidies (that act lowering costs) for each product and region can also be defined exogenously. There is a learning curve in the industry that could have been modelled as costs diminishing with accumulated production, but this effect is small or dubious compared to several other phenomena such as increasing or oscillating costs for land and energy, increasing environmental legislation which puts pressure on costs etc. So, as a simplification, costs are defined exogenously and can be tested in different scenarios. Nevertheless, there is an endogenous effect on costs that cannot be easily seen in the simplified diagram: as the demand and the market expand, more capacity is added in lower cost regions, mostly for hardwood instead of softwood. This trend naturally drives the average cost down.

The inventory coverage depends on the inventory and the demand. It is defined as the number of days of sales available in inventory at any given time. Its effect on the price depends on a reference value, or the coverage expected by the market. If the coverage is lower than the reference value the market interprets it as a potential shortage and the price starts to grow. If the coverage is bigger there is a surplus perception and prices start to fall. The reference value is not fixed. It does have upper and lower limits, but within this range it varies, following the current value with a long time constant. This dynamic occurs as the market "gets used" to the current levels. The inventory coverage connects all the main balancing feedback loops in Figure 5.

On the capacity side, an increase in prices will cause the expected mark-up and the capacity utilization to grow. More pulp will be produced as a consequence, which will fill the inventory at a larger rate and increase the inventory coverage. This increase will lower prices after a while, counteracting the initial effect and closing the negative loop "Capacity Utilization". The loop "Capacity Building" works in a similar way but with much bigger delays. An increase in prices will also increase the future expected profits which will prompt producers to build more capacity. After some years the new capacity will start producing, which will boost the inventory, increase coverage and bring prices down again, counteracting the initial dynamic.

On the demand side, the balancing loop "Demand Elasticity" acts relatively fast: as prices grow demand decreases according to the market elasticity. A lower demand increases coverage, which after a while will cause prices to fall, counteracting the initial change. The loop "Fibre Substitution" is slower. Paper producers work with equipment to process either softwood or hardwood. Some applications demand a single type of fibre, but others are more flexible. Nevertheless, if producers want to move from softwood to hardwood to take advantage of the price difference, they will probably have to change equipment or the process, which takes time. Because of this inertia, the preference for softwood is modelled as a stock that slowly changes depending on the price difference between the fibres. If the price of softwood begins to grow faster than of hardwood the preference starts to shift, which will increase the demand for hardwood in detriment of softwood. That will, *ceteris paribus*, decrease the inventory coverage of hardwood as opposed to softwood, thus increasing hardwood prices and lowering softwood's, which will counteract the initial imbalance.

At the capacity sector, building of new capacity starts when a new order is placed, adding to the stock of capacity on order. After an average time the building is complete and the flow acquisition rate adds to the current stock of capital. The capital is then discarded after an average lifetime. Several details are omitted from the diagram to avoid clutter such as: the average lifetime depends on the expected profitability

similarly to the desired capital (the relationships are non-linear); there are limits per region for the desired capital to account for available land; capital on order can be drained by cancellations if the desired capital falls suddenly, the order rate depends on the desired capital but also on a control for the current pipeline of projects.

Production starts with the flow `prodStartRate`, which adds to the stock of work in process. After an average production time the finished pulp leaves the WIP to add to the inventory, which is drained by the shipment rate. Shipments depend on the demand and on the ability to ship, given by the current levels of stock. The starts in production depend on the total capacity and on capacity utilization, which depends on the current mark-up and on the schedule pressure. Schedule pressure is the ratio between the desired production and the current production. It reflects the current expected demand plus adjustments for the inventory (based on the desired coverage) and for the WIP. These and other details are omitted in Figure 5 to avoid clutter.

At the demand sector, a regression model defines pulp consumption as a function of the population and GDP per capita (subject to an adjustable trend and upper/lower limits per region). The total market pulp consumption is then disaggregated into soft/hardwood according to the current preference for softwood as discussed previously. The result is an indicated demand for each product which translates into actual demand with a delay and according to the current price levels (compared to a reference price) and the demand elasticity. Changes in pulp consumption also prompt paper manufacturers to review their demand expectation and to change, apart from current orders, their inventory levels. This dynamics amplifies disturbances in the demand for pulp causing a "bullwhip effect" (Forrester J. W., 1961). This and other details are omitted from the simplified diagram.

The boundaries of the model are also depicted in the diagram in Figure 5 with the shaded variables representing the exogenous inputs. On the demand side, population and GDP are exogenous. Costs and the exchange rates for each region are also exogenous as explained previously.

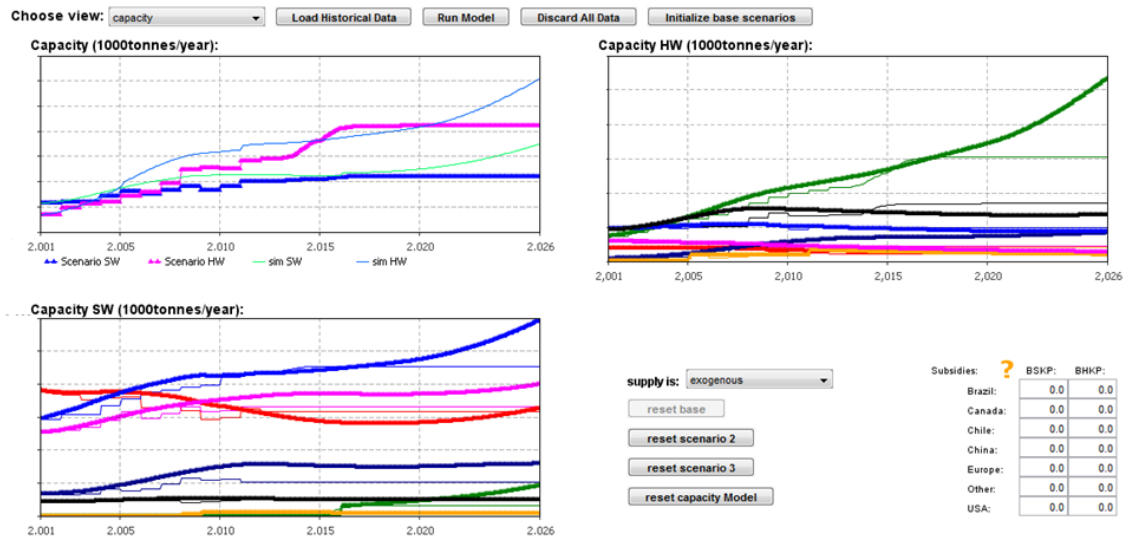
Regarding the capacity, it could be fully calculated endogenously (apart from the parameters which are all exogenous, of course) but the client also requires the option to manually set the capacity exogenously. New plants are announced well in advance, so the industry has a considerably clear picture of how the supply will evolve for at least the next seven years. Since the capacity increases in steps (roughly) with good estimates for the near future, a case is made for exogenous capacity. The simulator is actually equipped with a switch that allows the user to choose whether to run with endogenous or exogenous capacity. Typically the user runs a scenario with the known exogenous capacity and compares with the endogenous version. If there are large discrepancies in the results, it can be interpreted as a sign that the market is heading to a disequilibrium that will probably be corrected somehow (with plants closing, for instance).

The simulation interface allows the user to change all parameters and scenarios before running the model, and to explore all the results in time charts together with historical data and in multiple runs to enable comparisons. All the input data and the resulting output are stored in separate excel® files to facilitate data manipulation. Figure 6 shows a typical view of the simulator with the Capacity view¹. The charts show the input data defined by the user together with the results calculated by the model for comparison.

¹ All the results and data in this paper have been masked and the vertical scale removed from charts to preserve the client's intellectual property

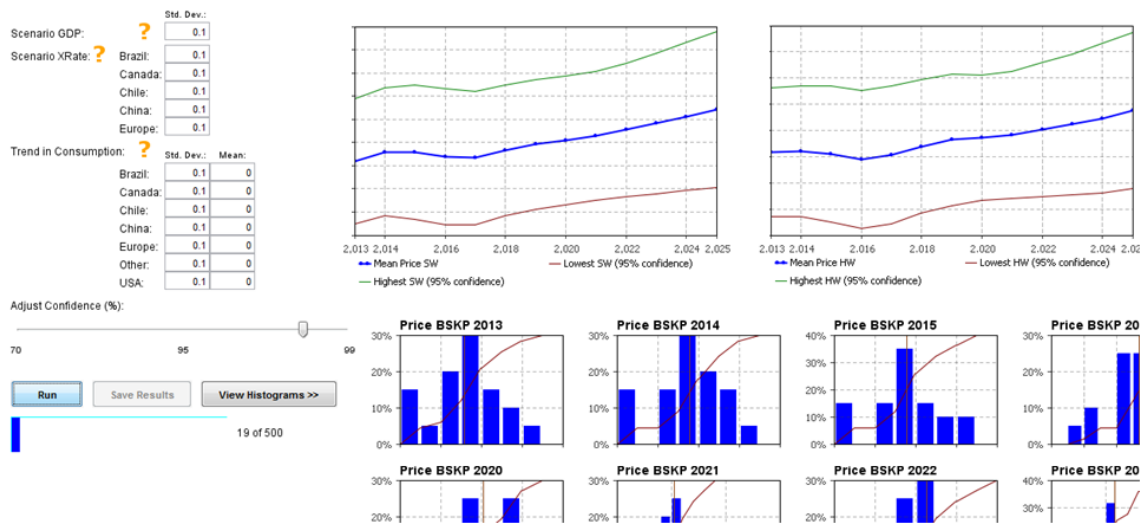
The interface also displays controls to select the capacity mode (exogenous x endogenous), to load different scenarios from the input file and to set subsidies.

Figure 6. Simulation interface: capacity view



All the input scenarios are subject to high uncertainty. A Monte Carlo simulation was developed to account for this uncertainty and to generate a range of expected prices for each year. Figure 7 shows the Monte Carlo simulation interface.

Figure 7. Monte Carlo simulation interface



The variables GDP, exchange rates and trend in pulp consumption per capita (by region) were selected as most critical due to uncertainty and influence in the results. The Monte Carlo simulation runs the model several times varying these parameters randomly but according to a normal distribution. For GDP and exchange rate, the base scenarios are assumed most likely, so the normal distribution has mean zero. The parameters vary with a standard deviation that can be changed in the interface (the default values were derived from historical data). For the trend in consumption both the mean and standard deviation can be changed in the interface, but the default values are also based on historical data. The resulting yearly average prices for each simulation are added to histograms and summarized in the charts above which show the expected range of prices according to the selected confidence level.

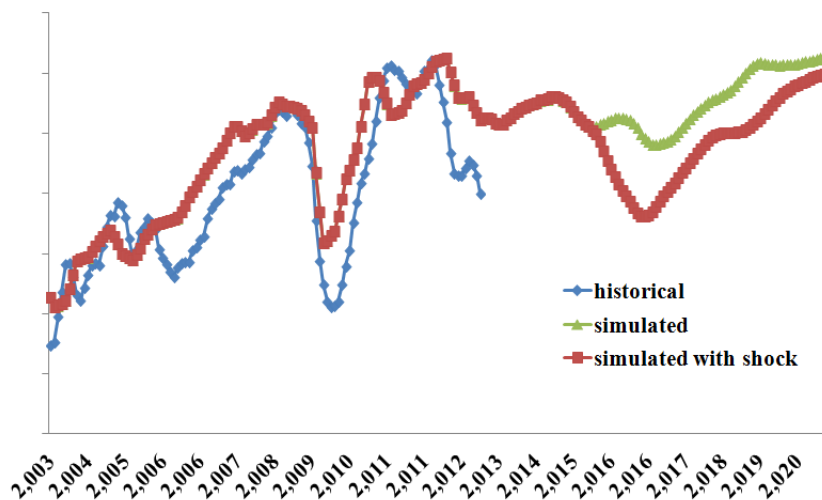
4. Simulations and Results

One of the main initial concerns was the validation of the model. Apart from several discussions with the client team to validate all the assumptions and other tests such as units checking, the main effort on this front was to reproduce the historical data satisfactorily. This was especially important because there is a vast amount of data available, not only of price but also capacity, shipments, production and inventory. The available data actually covers circa 80% of the total industry, so it was first necessary to estimate the full worldwide volumes for each pulp grade.

Next the model calibration was performed by several simulations with parameters variation until the reference mode was reproduced with minimal discrepancies (The simulated softwood price, for instance, explains close to 80% of the historical price). Because there is a good amount of data available, the model could be explored and calibrated as separate modules. Capacity and the demand could be supplied exogenously (therefore cutting the corresponding loops) so the production module could be carefully calibrated before the loops were plugged again and the full calibration could be performed.

Figure 8 shows one example of the simulation results for the price where the simulation can be compared to historical data. The model satisfactorily reproduces the swings in price after the global crises and the changes in capacity. The chart also shows an example of two runs being compared on the same chart. For this simulation random scenarios were chosen. For the second scenario, a global crisis is simulated with small to negative GDP growth in all regions during 2016. The results show the prices plummeting as a result of the simulated crisis.

Figure 8. Simulation results for price

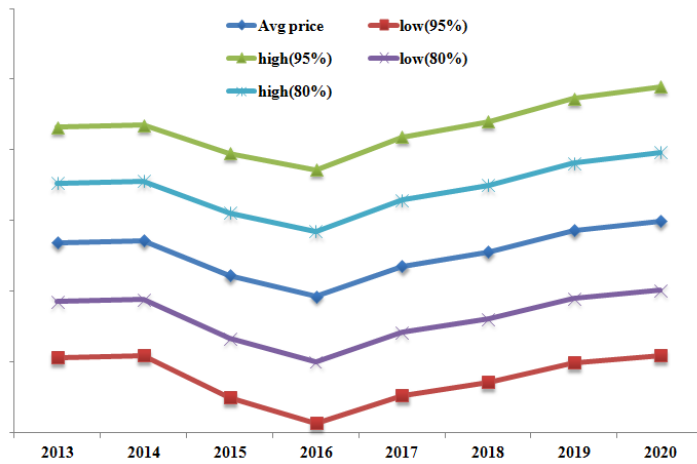


Historical prices, prices simulated in random scenarios and in the same scenarios with a negative shock in GDP in 2016. The vertical axis is suppressed to preserve the client's intellectual property.

Once the model was validated and several scenarios were generated, a set of base input scenarios believed to be the most likely to happen were selected. Those scenarios are loaded by default, together with all the parameters known to best calibrate the model. Therefore, once the simulator opens and runs without any changes, it generates a price scenario for hardwood and softwood that is regarded as the most likely. This scenario is to be reviewed with an interval of one to two months. The next question is "how likely is it really" or, in other words, what is the risk associated with this expected scenario?

To answer that question, a Monte Carlo simulation was developed as discussed in the previous section. A first step was to analyse historical data on GDP, exchange rates and trend in pulp consumption per capita in order to derive the approximate volatility. This analysis yielded the default standard deviations used to generate the Monte Carlo distribution of the input parameters. Figure 9 shows an example of the results. The average price is close to the most likely scenario. The highest and lowest expected prices for each year are then displayed for two confidence levels. The smaller range is expected to occur with an 80% confidence. In order to reach a higher confidence the expected range has to be enlarged considerably.

Figure 9. Monte Carlo simulation results: average price and variation range with different confidence levels.



The vertical axis is suppressed to preserve the client's intellectual property.

5. Conclusions

Monte Carlo simulations can be a powerful tool for risk assessment. By randomly varying the parameters independently, the simulation is actually generating a myriad of possible outcomes, some more likely than others, that will yield an expected distribution. Because each simulation is using the validated system dynamics model, there is a strong reason to believe that the outcome is very likely to remain within the limits generated by the analysis, especially when using a high level of confidence.

This project can also be studied as an interesting application of system dynamics. The use of exogenous data series and "loop cutting" proved to be an effective tool for model understanding and calibration. It is also interesting that the client chooses to use exogenous supply when the model can generate all the scenarios endogenously. It is important for the model to generate non-linear capacity starts, but also to display the supply curve in a familiar way, which suggests that it might be not always vital to "close the loop" in a working model (even though it was quite important during the modelling phase). The costs in this model are another example of "loop not worth closing".

It is also worth mentioning some details in this project regarding the user interaction with the model/simulator. All the exogenous inputs are defined in a separate spreadsheet, which enables the user to define scenarios with great flexibility. The scenarios that generated the results in Figure 8, for instance, were defined arbitrarily, the shock being manually entered. This scheme may also enable users to define scenarios with patterns and complex oscillations without the need for manipulation of the model which would require technical maintenance. Another example of usage is in the definition of exogenous capacity scenarios. A small sub-model was developed to

smooth the capacity starts (when a new mill starts producing) so they wouldn't look like a perfect step, since the mills never start with full operation. This sub-model was implemented within the spreadsheet, which allows the user to define different formats for the start curve, greatly increasing flexibility.

Finally, regarding the consulting process and model development, one must highlight the importance of client involvement for the project's success. The client team was fundamental for data collection and interpretation, and for concepts and results validation during the model development. More than that, it has been vital for ongoing exploration and analysis which contributed to make the whole process an actual learning exercise.

6. References

- FAO. (2012). *FAOSTAT*. Acesso em 21 de 2 de 2012, disponível em faostat.fao.org:
<http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor>
- FAO. (2010). *Pulp and paper capacities*. Retrieved mar 2013, from [fao.org](http://www.fao.org):
<http://www.fao.org/docrep/012/i1666t/i1666t00.pdf>
- Folha de Sao Paulo. (1994-2012). *Arquivos*. Retrieved 2012, from Folha de Sao Paulo:
<http://www1.folha.uol.com.br/folha/arquivos/>
- Forrester, J. W. (1961). *Industrial Dynamics*. Cambridge, Massachusetts: Wright-Allen Press.
- Index Mundi. (2013). *indexmundi.com*. Retrieved mar 2013, from Commodities Price Indices:
<http://www.indexmundi.com/commodities/?commodity=wood-pulp&months=180>
- Sterman, J. D. (2000). *Business Dynamics: System Thinking and Modeling for a Complex World*. New York: McGraw-Hill.