A Model of 'Breaking Bad': An Economic Model of Drugs and Population Dynamics Predicts how the TV Series Feeds Back to the Drug Market

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Abstract. The discusssed stock&flow-model predicts population dynamics of Crystal Meth addicts related to the price development of drugs, the society and the market that is affected by the popularity of the TV series 'Breaking Bad': The potential impact of the broadcasting of the TV series on the system is tested by using sudden (pulsed) changes of selected flows and rates to reveal sensitivity of selected variables: 'Addicts', 'price relationship', 'dealers' saturation' and 'Stock of Crystal Meth'. While consumption, purchase and production show strong responses to such perturbations, other variables like 'getting_addicted' and 'weaning_off' show only weak responses. These reactions to pulsed changes of model parameters are analysed and their significance is discussed.

Introduction and Motivation of the Model Study

Nowadays there are various addiction problems that are related to all types of different drugs. One dilemma is given by the fact that one cannot precisely illustrate how many drugs are circulating in the population due to the presence of the illegal drug market. Even though the police invest much effort into performing razzias, drug controls as well as fighting the drug war, the illegal drug market persists with its vast sum of different drugs [1-3].

Economy, however, exploits the 'popularity' of the drug war to produce films or series, although it might be sociologically beneficial [4] to produce educational or documentary films that explain the drug problematic as well as creating awareness to get down to the root of the trouble which is lack of knowledge and downplaying drug effects [1].

Such alternative programs could help to avoid drug addiction or to abandon drugs [1,4].

The presence of these illegal substances causes a huge amount of different effects. On the one hand some agents make a huge profit out of their famousness, while others profit from selling drugs.

On the other hand there is a vast amount of people affected by the drug problematic via illnesses, gang shootings, financial ruin, and many other problems. [1-3]

The methamphetamine Crystal Meth is a long known substance [5] that suddenly increased its fame in the year 2008, due to the TV show 'Breaking Bad' (2008-2012) [3,5-7]. This TV series shows a school chemistry teacher who starts producing and selling Crystal Meth in order to earn money. Blake Ewing, an assistant district attorney, once said: '*I'll continue to wonder about the long term effects of mainstreaming such a dangerous drug into popular culture'* [8].

In 2012 the Crystal Meth consumption increased and exceeded the number of heroin users [9]. We hypothesise that series like 'Breaking Bad' (2008-2012) may have catalysed this increase of Crystal Meth, as series like 'Breaking Bad' (2008-2012) are assumed make drugs more tempting for teenagers or potential sellers and thus increase the addiction rate ultimately.

In general it is extremely difficult to examine how drug availability itself or hypes induced by series like 'Breaking Bad' (2008-2012) affect a population's use of drugs.

In order to gain insights into the socioeconomics of the drug market we built a mathematical model (Figure 1) and ran multiple analyses to describe this kind of dilemma in quantitative predictions.

1 The Model

Our mathematical model (Figure 1) is based on a simple economic model representing the dynamic ratio of supply and demand. It predicts flows of drugs to and from addicts and drug dynamics in correlation to the given price development assuming that the latter regulates the established market by making drug-selling more attractive due to a greater demand. We used this mathematical model to predict the system's sensitivity to outside influences such as the influence of the TV series 'Breaking Bad' on the modelled drug market is assumed to have. We tested this hypothesis based on the assumption that, due to the series broadcast the amount of people cooking or trying out Crystal Meth will change. We furthermore assumed that the number of dealers who switch to selling this drug will be affected in consequence of the TV series. These sudden extrinsic perturbances of the beforehand established equilibria of the system variables were simulated by PULSE functions which are defined by (1), whereby t is the time where the data are observed, t_{start} defines the begin of the PULSE, *dur* defines the length and *amp* defines the amplitude of the PULSE.

It is important to understand that our article does not model the fictional drug market based on what is shown in the TV series. Instead we elaborated an economic model of the real-world drug market and tested the effect of the hype that a series like 'Breaking Bad' may have on this market system.

1.1 Methods

The stock&flow-model [10,11] is built in Vensim 5.11A [11]. This programme is available as free download on http://vensim.com/free-download/ [11]. The model works with data that are parameterised with data from the world drug report [12], and other literature sources [13,14].

The model runs for 120 months, integration type is Euler [14] and time step is defined with $\Delta t=0.1$ month. Units for CrystalMeth. are [g], units for *Addicts* (N_a) and *Non_Addicted* (N_{na}) are [persons]. The models' main structure is shown in Figure 1. The total *Stock of Crystal Meth* (C_{stock}) is specified by (2) where α is the *intrinsic production rate*, g represents the *smuggled goods*, β is the *actual purchasing rate* and C_{circ} is the amount of *Crystal Meth in Circulation*. *Crystal Meth in Circulation* is defined by (3) that follows from the constant *actual purchasing rate* β, *consumption rate* γ and *distribution rate* λ.

The dynamics of N_{na} are modelled by (4), where the *actual growth rate* is δ, *normal death rate* is ε, *weaning off rate* is μ, *addiction rate* is φ and the *dealers' saturation of crystal meth* is s.

Equation 5 determines the dynamics of N_a that grow in number with φ and s and drop with μ and drug related death rate ω. The *purchasing price relationship* p is a regulator for the drug flow; it is defined by supply – C_{stock} - and demand – N_a, s, γ and r- the *daily requirement*. The *price elasticity* a is a measurement for the responsiveness of a good to a change in its price. These relationships are described in (6).

The *dealers' saturation* s has influence on *consumption* and on p, as apparent from (7). The *dealers' saturation* also regulates the *getting_addicted* and the *weaning_off* flow. A 100% dealers' saturation implies a maximum addiction rate. Thus forming the link between drugs and addicts. *Equation 7* is given by (7) where C_{circ} is given in (3) and k is the *dealers' maximum capacity*.

A PULSE function (1) was used to test the drug system's sensitivity to the series' influence. The series ran for 5 years, thus we applied the PULSE for 5 years to perturb the system with different strengths (0% to +50%). Therefore (1) was used, where the data at $t=73$ are observed, t_{start} is 13 [month], duration is 60 [month] and the amplitudes are the different strengths multiplied to the *default value*, thus a factor of 1.0 represents 0% and a factor of 1.5 represents +50% of perturbation strength. So this pulse function changes a chosen flow in a defined time interval of duration *dur* ranging from t_{start} to (t_{start} + *dur*) by multiplication. For example: We enhance the production of Crystal Meth about 20% in every time step for a defined time-period.

1.2 Experiments

In order to predict the effect of the broadcast of the TV series onto the various system components we performed a set of perturbation experiments. *Equation 8* describes in general how the PULSE function (1) was used to change a chosen system variable by applying a *perturbation factor* (*pf*). Whereby we used the *default values* (*dv*) given in *table 1* for every perturbed system variable.

We assume that the broadcast of the TV show and its popular reception can make the drug more attractive, lower the barriers to get the drug and thus will increase the probability of potential consumers to become addicts. This is expressed by perturbing the variable '*getting_addicted*' as described by (9).

We supposed that due to the broadcast of the TV show the tendency to wean off drugs might decrease because being addicted becomes popular. This is expressed by perturbing the variable '*weaning off*' in the following way, see (10).

We further assumed that the TV series can increase consumption since more people want to try out this popular drug. This is expressed by perturbing the variable '*consumption*' in the way as is described by (11).

We assumed that 'Breaking Bad' makes it attractive for dealers to switch to selling meth instead of other drugs. This is expressed by perturbing the variable '*purchase*' in the way as it is described by (12).

We also supposed that the TV series motivates people to establish their own 'Meth-lab' [16]. This is expressed by perturbing the system variable '*production*' in the way, as it is described by (13).

Following these assumptions we did four experiments to test how variables react to our assumed effects of the series.

<u>Experiment 1</u>: We disturbed the flows (as described above) with different amplitudes of perturbation PULSEs and examined how *Addicts* react on these disturbances.

<u>Experiment 2</u>: We observed the *purchasing price relationship* while disturbing flows (as described above) via different amplitudes of perturbation PULSEs.

<u>Experiment 3</u>: We disturbed the flows (as described above) with different amplitudes of perturbation PULSEs and studied how *dealers' saturation of crystal meth* was influenced.

<u>Experiment 4</u>: We investigated the *Stock of Crystal Meth* while disturbing the flows, which are described above, via different amplitudes of perturbation PULSEs.

1.3 Results

Figure 2 shows the reactions of *Addicts*, *purchasing price relationship, dealers' saturation* and *Stock of Crystal Meth* after the PULSE influenced the affected flows. The abscissa shows the increase and the decrease of the PULSE effect relative to the starting conditions. The ordinate shows the relative change of the observed variables. In general, responses are almost linear.

<u>Experiment 1</u>: When changing the *getting_addicted* flow the stock of *Addicts* reacts by increasing in number, while a change of *consumption* decreases *Addicts*. *Purchase* and *production* show less reaction and similar linear scaling of reaction.

<u>Experiment 2</u>: The *price relationship* increases with a positive change in purchase and decreases with a rise in *production*. *Getting_addicted* shows a slight increase, while *production* is reacting least to a change.

<u>Experiment 3</u>: *Dealers' saturation* grows strongest with a rise in *production* and decreases with an increase in *consumption*; with changes in *getting_addicted* and *purchase. Dealers' saturation* shows little decrease.

<u>Experiment 4</u>: The *Stock of Crystal Meth* is most influenced by increased *production* volumes and by decreased *purchase*. The *consumption* and *production* flow show similar linear responses, but on a low level.

None of the observed variables react to changes in *weaning_off*; this flow remains constant throughout all perturbation experiments.

1.4 Discussion

System Dynamics is a method for analysing complex and dynamic systems to understand and if necessary to manipulate a systems' behaviour [10]. Therefore it is applicable in many scientific disciplines such as biology, sociology and economic sciences. The System Dynamics approach aims for recognising essential and global contexts. Vensim PLE is a simulation software for developing, analysing, and packaging dynamic feedback models. [11] It was chosen due to its simplicity in setup and application. Furthermore profound / extensive mathematical skills can be neglected for the benefit of joined-up thinking / system comprehension. Therefore it perfectly fits for beginners to get an insight into the modelling process.

The model itself is based on basic economic regulations concerning supply, demand and price-development – if demand and supply are equal, the market is stable established by the price, which is the balancing variable. Secondly, population dynamics are simply described by birth and dying events - outside influences such as immigration are disregarded in order to maintain a closed system. Due to these facts the modelled system reacts due to system-intrinsic feedback loops. On the one hand, we showed that the modelled drug market is intrinsically stable in response to extrinsic perturbations.

On the other hand, significant medium-term effects of perturbations are predicted, as they can be caused by the TV series itself. These responses, which are shifts of equilibria during the perturbed period, have been analysed systematically in a quantitative way generating testable hypotheses.

Results show different sensitivities of analysed observed variables to the changes in parameters governing important flows in the system: The more *consumption* increases, the more *dealers’ saturation* decreases. Consequently the *price relationship* and *Addicts* decrease. This seems implausible at first sight but it is accurate according to the model’s hypothesis of market regulation. Since demand is determined by the *consumption rate* and not by the *consumption* flow, the *price relationship* does not react as one might initially expect. The saturation reacts with a time delay, which is a result of the multi-stock structure of the modelled system. With regard to *production*, the model’s behaviour is governed by the feedback loop ‘*Stock of Crystal Meth to purchase*’, which prevents oversaturation.

The growing *purchase* flow reacts with an enhancement of *Addicts*, *price relationship* and *dealers’ saturation* while *Stock of Crystal Meth* decreases. This is consistent to the underlying hypothesis of market regulation.

A positive change in *getting_addicted* leads to an increase in *Addicts*. As *price relationship* is not very responsive to small changes, it grows subtly, due to a remote growth in supply (*Stock of Crystal Meth*).

Dealers’ saturation decreases with higher *consumption* caused by more *Addicts*. *Weaning_off* conspicuously is insensitive in consequence of a low *weaning_off rate*.

Since there are no over-proportional changes the system is considered to be stable. This stability is caused by the negative feedback loop established by the interaction of demand and *price relationship*. The higher the *price elasticity* (6) is, the more stable the system becomes due to a higher flexibility in the *price relationship*, which induces an enhancement of the negative feedback loop.

One simulated perturbation of the drug market was found to be the effect of the broadcast of the series itself [8]. In agreement to our model predictions, the UNODC reports an increase in *Stock of Crystal Meth*, *Addicts* and *Crystal Meth in Circulation* between 2008-2012 [12, Fig. 49.].

Based on our results it can be assumed that ‘Breaking Bad’ still has an impact on the rise in meth-use. State-Time plots (not shown here) indicate long-term effects, concerning the ratio of *Non-addicted* to *Addicts* without a decrease of total population. *Addicts* become more while *Non-Addicted* decline in amount. Apart from these changes the model - in the long term - finds back to its starting conditions. We did not consider the fact that the series is still in circulation (e.g. streaming sites) and thus its effects may endure even longer.

It is remarkable that the *price relationship* always reaches its equilibrium after the pulse-shaped disturbance of the system ceases to act on an altered flow. This is a consequence of (6) which varies the terminal point by alternating the *price elasticity* a in a self-stabilizing way.

Since there is no data that strictly reports about a correlation between the series and the increase of seizures of *CrystalMeth* reported by the UNODC the model cannot be strongly validated by directly comparing to empirical data. However, we think the model’s mechanisms are generalizable to any hype-affected drug market thus useful future work can replace *CrystalMeth* by Marihuana- since more data is available due to its actuality concerning legalisation. By doing this, the effects of such a legalising could be modelled and then be compared with data of countries that already legalised it- such as, for example, Portugal. The core piece of work, a solid but still simple economic drug market model, is developed and analysed in the current paper.

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2 Model Equations

$$PULSE(t, t_{start}, dur, amp) = \begin{cases} 0 & if\ t < t_{start} \\ amp & if\ t_{start} \le t < (t_{start} + dur) \\ 0 & else \end{cases} \quad (1)$$

$$\frac{\Delta C_{stock}}{\Delta t} = +\alpha(t) * C_{stock} + g(t) - \beta(t) * C_{stock} * \left(1 - \frac{C_{circ}}{k(t)}\right) \quad (2)$$

$$\frac{\Delta C_{circ}}{\Delta t} = +\beta(t) * C_{stock} * \left(1 - \frac{C_{circ}}{k(t)}\right) - MIN\left\{ \begin{matrix} C_{circ} * d \\ \gamma(t) * N_a * s(t) \end{matrix} \right\} \quad (3)$$

$$\frac{\Delta N_{na}}{\Delta t} = +\delta(t) * N_{na} + \mu(t) * N_a * (1 - s(t)) - \varphi(t) * N_{na} * s(t) \quad (4)$$

$$\frac{\Delta N_a}{\Delta t} = +\varphi(t) * N_{na} * s(t) - \mu(t) * N_a * (1 - s(t)) - \omega(t) * N_a \quad (5)$$

$$p = \frac{a * \frac{N_a * (1 - s(t)) * \gamma(t) * r(t)}{C_{stock} + 1}}{\sqrt{1 + \left(a * \frac{N_a * (1 - s(t)) * \gamma(t) * r(t)}{C_{stock} + 1}\right)^2}} \quad (6)$$

$$s = \frac{C_{circ}}{k(t)} \quad (7)$$

$$pf(t) = dv * PULSE(t, t_{start}, dur, amp) \quad (8)$$

$$getting\_addicted(t) = N_{na} * \varphi * s * PULSE(t, t_{start}, dur, amp) \quad (9)$$

$$weaning\_off(t) = N_a * \mu * s * PULSE(t, t_{start}, dur, amp) \quad (10)$$

$$consumption(t) = \lambda * C_{circ} * s * \gamma * PULSE(t, t_{start}, dur, amp) \quad (11)$$

$$purchase(t) = \beta * k * C_{stock} * C_{circ} * PULSE(t, t_{start}, dur, amp) \quad (12)$$

$$production(t) = \alpha * C_{stock} * PULSE(t, t_{start}, dur, amp) \quad (13)$$

3 Figures

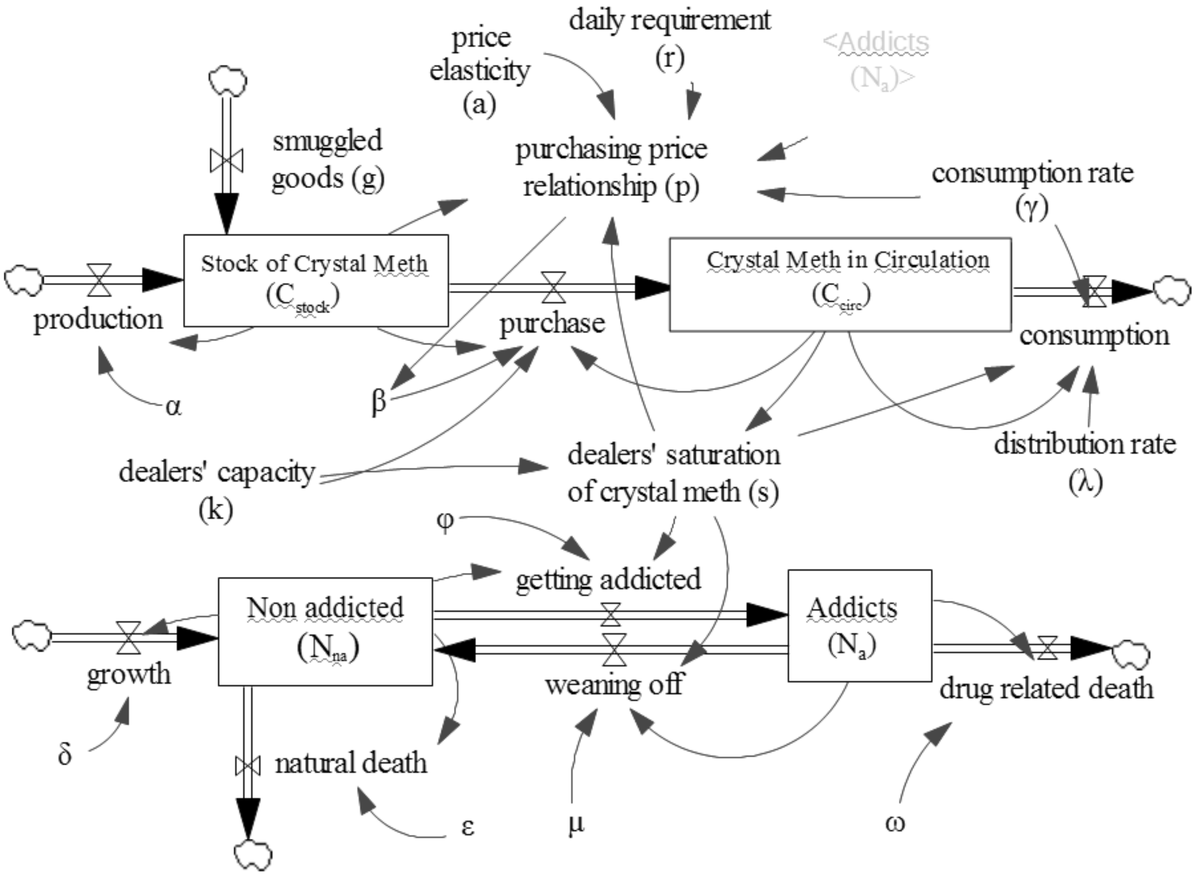

Figure 1: Excerpt of the stock&flow-model of drugs and population dynamics, showing the main structure of its system components:

Rectanglular boxes depict stocks, that are system components that model quantities that can only change through flows (double arrows) that bring quantities from sources (cloud symbols) into the system or via sinks (cloud symbols) out of the system. The whole chain of sources, flows, stocks and sinks guarantees conservation of mass in the system. Thin singular arrows indicate positive or negative direct dependencies between system components, which can be either constants (greek letters) or variables (latin letters). For further details, see text.

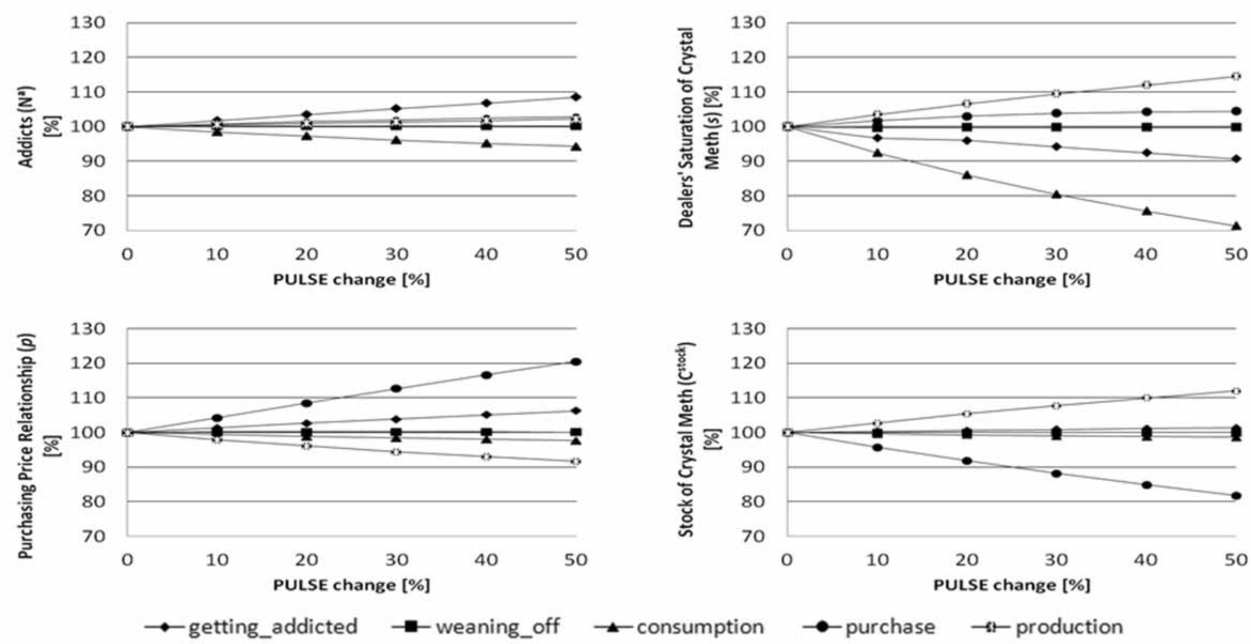

Figure 2: Results of sensitivity tested by a pulsed disturbance of model parameters: Each picture depicts the effect of the applied pulse distribution on the abscissa. a) The stock of *Addicts*, b) the variables *Purchasing Price Relationship*, c) the variable *Dealer' Saturation of Crystal Meth*, and d) the *Stock of Crystal Meth* are depicted on the ordinate. All values are in percent. For further details, see text.

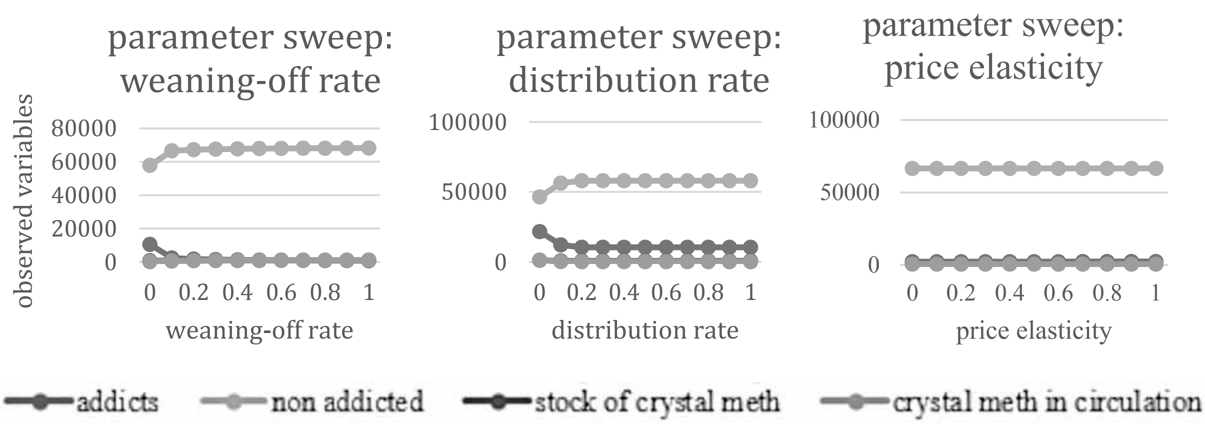

Figure 3: Parameter sweeps of the parameters weaning-off rate, *distribution rate and price elasticity* in the standard-model. We analysed how the stocks in our model react to different rates ranging from 0.0-1.0 (x-axis). The y-axis shows the observed data of *Addicts*, *Non-addicted, Stock of Crystal Meth* and *Crystal Meth in Circulation* at t=73. In the range of 0.0 and 0.2 of the varied parameter the observed variables are most sensitive to changes.

4 Used Parameters

Variable	Initial value	Unit	Literature sources
Actual growth rate (of non addicts) δ	0.011668	1/Month	0.014/Year [14]
Addiction rate φ	0.01	1/Month	0.012/Year [12]
Basic purchasing rate β	0.4	1/Month	50.000g/500.000 Addicts/Week [12]
Consumption rate γ	0.04	g/Person/ Month	15mg/Person/Day [12]
Daily requirement r	15mg	1/Person	15mg/Person/Day [15]
Dealers' capacity k	300	g	[15]
Distribution rate λ	0.5	1/Month	Free parameter[1]
Drug related death ω	0.00001	1/Month	0.000147 Persons/Year [15]
Intrinsic production rate α	0.8	1/Month	10 tons/Year [15]
Normal death rate ε	0.000683	1/Month	0.0082/Year [14]
Price elasticity a	1	dmnl	0nly price relationship is sensitive
Smuggled goods g	16000	g/Month	0.2 tons/Year [12]
Weaning off rate μ	0.1	1/Month	Free parameter[1]

Table 1: Variables, initial values , units and literature sources used in the model. Data originates from the World Drug report 2014 [12], the United States Census Bureau [13] and Härtel-Petri and Haupt [14].
[1] model is highly sensitive in [0.0-0.2] and insensitive in [0.2-1] to those parameters. The parameter sweeps are depicted in Figure 3-5.

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