PETRI NETS AS TOOLS FOR POLICY ANALYSIS: THE EXAMPLE OF SMOKING BANS IN PUBLIC PLACES

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ABSTRACT

Petri nets were originally developed in order to describe concurrent processes in computers and other automata. This paper identifies the features of Petri nets, which are essential for doing semi-quantitative analyses of public policies. The toolkit resulting from this methodological investigation is subsequently used for an exemplary analysis of smoking-bans and -restrictions in public places. At the end, the article presents empirical evidence, which seems to corroborate some inferences deduced from the model.

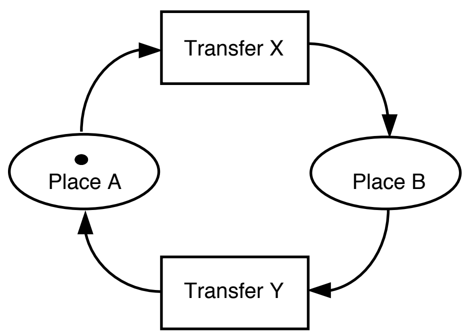
INTRODUCTION

This article proposes to use *Petri nets* (Van der Aalst and Stahl 2011: chap. 3; Wang 1998: chap. 2) for modelling *public* policies (Dunn 2004: chap. 2; Parsons 1997: chap. 3; Rossi and Freeman 1993: chap. 1). At first, the two topics seem to be rather disparate. *Public policy analysis* deals with political processes like the introduction of smoking bans or other measures for the promotion of public health. Among others, public policy analysis asks about

a) the political and social *processes* required for explaining the existence or non-existence of certain public policies in different national contexts;
b) the *feasibility* of planned new policy-goals;
c) the existence of *concurrent harmful processes,* which may unintentionally be triggered by new policies.

Petri nets – on the other hand – have been developed for describing technical systems like computers or vending automata. They use for this purpose a special graphical language, which allows to model the transfers of so called tokens or objects from one place in the system to another. Fig. 1 depicts such an exemplary network, where tokens are being moved between two places A and B by cyclical transfers X and Y.

In spite of these differences, Petri nets reveal to have functionalities, which make them much more useful for policy analysis than originally thought (Heitsch et al. 2001; Koehler et al. 2001a; Koehler et al. 2001b). Like public policy analysis, Petri nets are *process-oriented.* They are especially made for describing *concurrent* processes, which are also a major concern of public policy analysis: as mentioned before, public policy analysis has e.g. an interest in the unintended consequences of new policies, which often run in parallel with their implementation. Similarly, it often occurs that new policies can only be put into effect, if concurrent secular processes like the availability of material resources or popular support have reached a certain stage. Besides, a branch of Petri net analysis focuses on the *reachability* of goals or places (Wang 1998: chap. 2.4.1), which promises to be also of use for feasibility studies in political planning. Finally, Petri nets can be used for modelling networks with *limited transfer capacities,* which is obviously also an important topic for the implementation of new public policies in state agencies.



Legend: ●: Token, being cyclically transferred between places A and B.

Fig. 1: A small exemplary Petri net.

All these communalities justify to consider Petri nets as potential tools for public policy analyses. Hence, this paper will first identify those *features* of Petri net analysis that are especially useful for modelling and investigating public policies. These features will then be used for analysing an exemplary case: the European anti-smoking policies, which have been put into effect

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in the last 25 years, in order to prevent passive smoking in public places (see Goel and Nelson 2008).

PETRI NET MODELS FOR PUBLIC POLICY ANALYSIS

The Main Elements for Constructing Social Models

As mentioned before, Petri nets have been developed for describing and analysing technical systems. Consequently, when being used for public policy analysis, at least some of their features require an appropriate adaptation to the *specificities of social sciences,* which will be given in the sections that follow.

One of the central concepts of Petri nets are *tokens,* that can be „anything“ and may even have different qualities in the same model. The *main* category of tokens for policy analysis are *social problems,* which are transferred from one institution or office of the state to the next in order to be transformed into solutions. At the higher level of abstraction, which refers to *policy making,* tokens are *requests* from the public and the final outcome of the mentioned successive transformations are new *laws* or new administrative *procedures.* At the lower level of abstraction, mainly referring to *policy application,* social problems are *cases* like e.g. individuals, which lose by successive transformations by state agencies, such as prisons or unemployment offices, their problematic facets. Obviously, there are also *subsidiary* „technical“ tokens, which are required to model concurrent social processes, like e.g. the availability of power, money, etc. They often have system specific numerical values and thus create a *coloured* Petri net (see e.g. Jensen 1992: chap. 2.1).

Another central concept of Petri nets are *places.* For policy analysis we will consider them as *political institutions* or *state agencies.* Contrary to the situation in technical Petri net analysis, the incumbents of places have intentions and plans, which sometimes are even in conflict with the plans represented by other places. Consequently five types of particular graphic network elements are especially important for policy analyses:

a) *Priorities* of alternative transfers of tokens, indicated by *i, ii, ... ,* etc. In Fig. 2 e.g., the incumbent of place C has a preference for transfer Z1 over transfer Z2.

b) *Inhibitions* of transfers. In the exemplary Fig. 2, the token at place A is able to inhibit the transfer W.

c) *Triggers* of transfers. In Fig. 2 e.g., the token at place A is also able to trigger the transfer X.

d) Tokens with *time dependent* numerical values, which have a *white* filling. In the exemplary Fig. 2 there is such a token at place A, where it may be used for describing a secular development of a political system.

e) *Capacities* of places for the simultaneous *treatment* of social problems. In Petri net diagrams they are indicated by small bold figures **1**, **2**, ... assigned to places like B or C in Fig. 2, which consequently can host the number of tokens corresponding to these figures. If there is no explicit information about the treatment-capacity of an agency or political institution, it is by default equal to 1.

With the mentioned special elements (a) to (e) and the standard symbols for tokens, places, and transfers, it should be possible to construct a qualitative model of nearly any policy process. Useful for this kind qualitative modelling are not only the theoretical literature but also abstractions from typical cases. Hence, Petri net modelling is relatively close to established *qualitative research* techniques like *grounded theory* (Strauss and Corbin 1998) or *qualitative comparative analysis* (QCA) (Ragin 2007). Petri net modelling for policy analysis may however also have *quantitative* facets: transfers may e.g. be triggered, if the time-dependent value v of a white-coloured token falls below a certain threshold e (see Fig. 2, place A). In the latter case, classical statistical research techniques like logistic regression (see e.g. Aldrich and Nelson 1992) may become important for *estimating* the values of these thresholds.

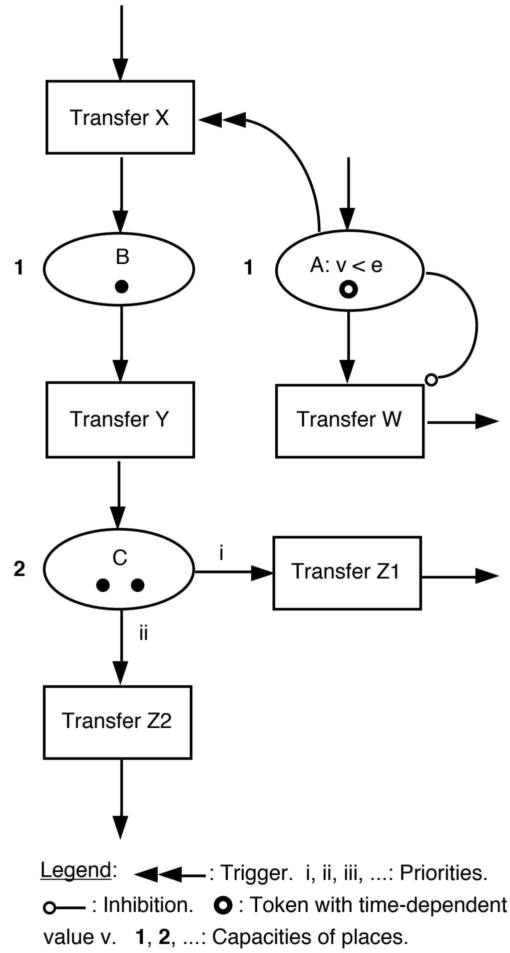


Fig. 2: Essential elements of Petri nets for public policy analysis.

Model Exploration and Model Testing

Petri nets can be „fed“ with two types of tokens: *Empirical* tokens with observational data from real politics and *experimental* tokens with fictitious values and properties. Empirical tokens are generally used for *model testing:* here, the focus is on the correspondence between the outcome of the model and the related empirical observations, often evaluated by conventional statistical test procedures (see e.g. Newcomer 1994). To the contrary, *experimental* tokens are primarily for model *exploration,* which means in this context ex-ante and ex-post evaluation. Experimental tokens allow to assess ex-ante the *feasibility* of new policies as well as their *unintended negative consequences.* By means of experimental tokens, it is also possible to *criticise* past policies, e.g. if an ex-post analysis reveals that there would have been better alternatives.

Model exploration with experimental tokens is traditionally done „by hand“ (see e.g. Reisig and Rozenberg 1998). In computer science there is a long tradition of mathematical reasoning in order to proof e.g. that certain places within a Petri net are reachable or absorbing deadlocks. This intellectual tradition is certainly also useful for the analysis of Petri net models of public policies. With only a small mathematical effort it is e.g. possible to evaluate the reachability of goals and thus the feasibility of the corresponding policy.

However, if empirical tokens are used to test a model with a great number of real cases, mathematical „handwork“ can be tedious. In this situation it is advisable to *simulate* the dynamics of a model. The database of Heitmann (2013) mentions for this purpose a great number of specialised software products. Alternatively, the much better known EXCEL may also be used for such investigations. In this case, the *lines* of the EXCEL spreadsheet represent subsequent time-points, whereas the *columns* are Petri net places with codes 0, 1, 2, … , representing the number of tokens, by which they are occupied at a given time-point. Once the essential parts of a Petri net model are programmed, its long-term dynamics can be explored by iteratively repeating this program-nucleus with EXCEL‘s copy-paste function. Needless to say that such an EXCEL program is also very useful for trial-and-error optimisation of policies.

AN EXEMPLARY APPLICATION: SMOKING BANS

The Explanandum

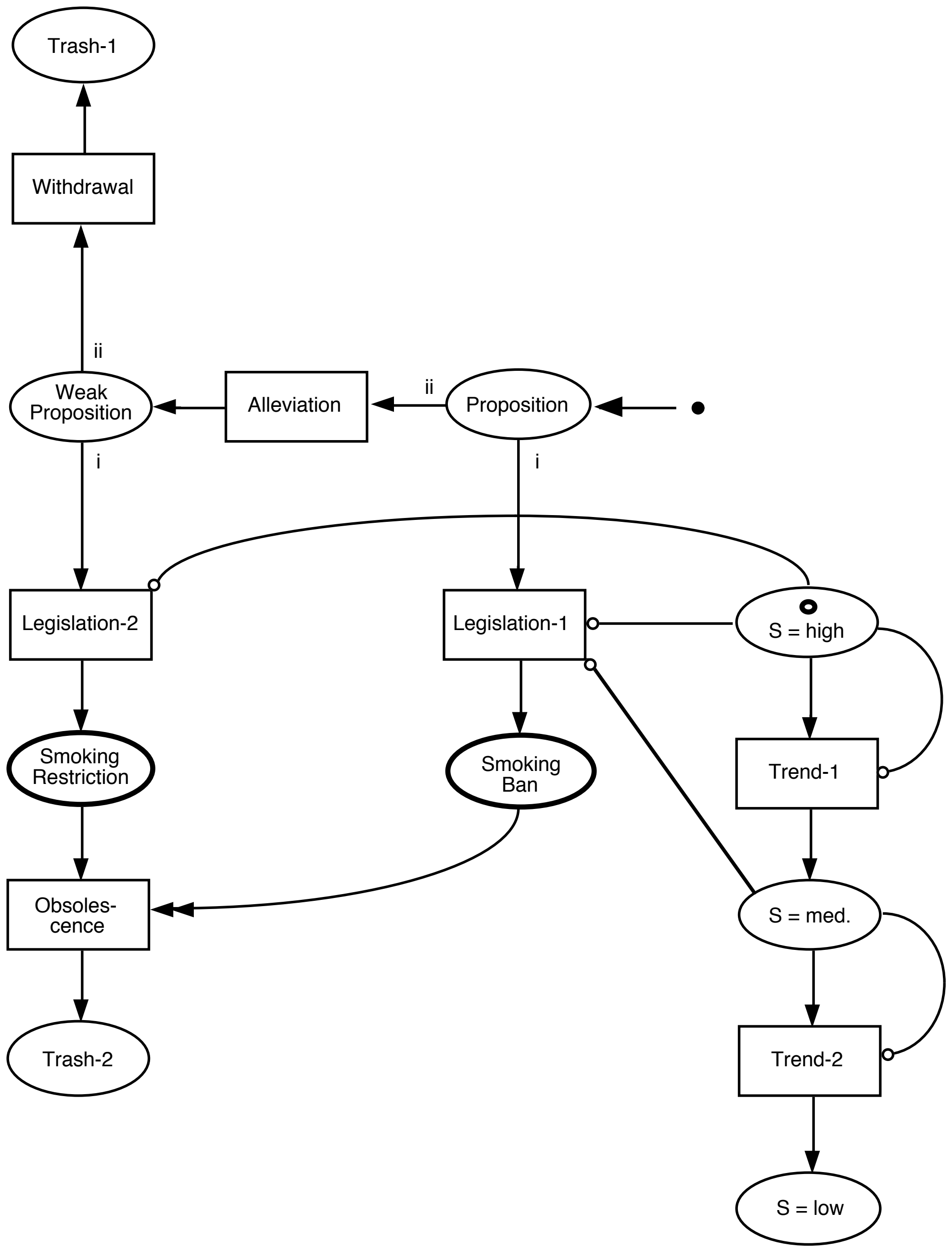
For many years, tobacco taxes have been the main instrument for controlling the consequences of excessive smoking behaviour (Goel and Nelson 2008: chap. 2). Since this policy was obviously not very efficient in protecting non-smokers against nicotine abuse by others, many governments introduced after 1990 smoking restrictions and smoking bans in public places like restaurants, railway stations, etc. (Goel and Nelson 2008: chap. 7; WHO 2007: part 2). As analysed by the author in an earlier publication (Mueller 2013), preventive measures against passive smoking generally started with smoking restrictions, e.g. by the introduction of smoke-free zones. A few years later, such policies were often replaced by total smoking bans in public places. In the mentioned publication the author was able to show that the schedule of this process depends on the *share of the smokers* in the total adult population. In democratic countries, smokers have voting power in parliamentary elections, which has to be considered by the legislators. Consequently, the higher the share of smokers in the adult population, the slower the stepwise process from*, unrestricted smoking* to *smoking restrictions* and finally to *smoking bans.* In what follows, we will describe this process by a Petri net model, among others in order to explain the different national histories of smoking-bans and -restrictions.

The Model

The model, which we propose in Fig. 3 for explaining the introduction of smoking-bans and -restrictions is driven by two *concurrent* processes. The first refers to the processing of *black* tokens representing anti-smoking proposals by the political system. The second process describes the “demography” of smokers and non-smokers by means of a *white* token, which represents the *smoking rate S,* i.e. the percentage of the adult national population, which is regularly smoking. This process is considered to be rather autonomous, i.e. not directly influenced by smoking bans, but rather by cultural factors like e.g. the spread of healthier life-styles.

At the start t_0 of the process, the *white token* is always in the top-category „S=high“. Thus we assume that smoking rates were in the 1980-ies anywhere in Europe relatively high and tended to drop only in the subsequent years to the currently observed lower levels. The second part of this assumption means that the white token systematically decreases its value over time, until it falls below a threshold e‘, which separates the high smoking rates from the others. Consequently, „Trend-1“ in Fig. 3 is no more inhibited and the token is transferred to the correct medium category of smoking „S=med.“. By a further decrease, the smoking rate finally falls below a second threshold e such that the inhibition of „Trend-2“ is also lifted and the token drops into the final category „S=low“.

As Fig. 3 demonstrates, the afore-mentioned dynamics of the share of the smokers has immediate consequences for the processing of new anti-smoking propositions, depicted as *black tokens.* As long as the smoking rate is high and „S=high“ is occupied by a white token, both transfers „Legislation-1“ and „Legislation-2“ are blocked by a strong smoking-lobby and propositions cannot be transformed in a legally binding „Smoking Ban“ or „Smoking Restriction“. Consequently, new propositions will be withdrawn and thus go to „Trash-1“. As soon as the smoking rate drops to the medium level „S=med.“, the inhibition of „Legislation-2“ is lifted and a „Smoking Restriction“ becomes possible. Thus, after an „Alleviation“ of the initial proposal that makes it politically more acceptable to the shrinking share of smokers, the policy maker follows its first priority i and realises a „Smoking Restriction“. If at the end of long secular process the white token is in category „S=low“, the electoral power of the smokers is so weak that not only „Smoking Restriction“ but also „Smoking Ban“ are viable policies, since in this situation all inhibitions of „Legislation-1“ and „Legislation-2“ are lifted. It is assumed that the policy maker has an interest in strong anti-smoking laws and consequently follows its priority i: Instead of proceeding to the „Alleviation“ of new proposals, they are transferred to „Legislation-1“ and put into effect as „Smoking Bans“. As indicated in Fig. 3, this triggers the „Obsolescence“ of older smoking restrictions, which are consequently suspended.



Legend: S = Smoking rate. S=high: S≥e‘. S=med.: e‘>S≥e. S=low: S<e. Other symbols: See text and Fig. 2.

Fig. 3: A Petri net model of smoking-bans and -restrictions:
The situation at time t_0.

Some Inferences from the Model

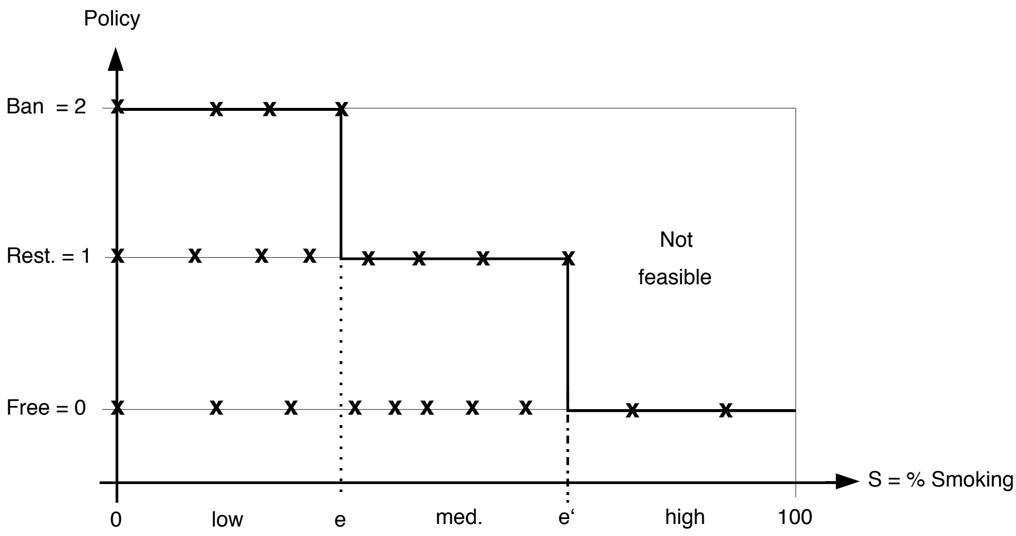
In principle, it would be possible to translate Fig. 3 into an EXCEL program that simulates the processing of artificial and real country tokens. However, inferences extracted this way are often not very transparent, mainly due to the absence of rationales. Hence, we preferred to do the simulation „by hand“ and extracted this way four major results:

a) The way from „free“, unrestricted smoking to smoking restrictions and smoking bans is *unidirectional* with no possibility to return to an earlier stage in this sequence. This is a consequence of the unidirectional decrease from high to low smoking rates as well as of the preferences of the policy maker for more restrictive anti-smoking measures.

b) It is very *unlikely* that in the afore-mentioned sequence of smoking policies the stage of *smoking restrictions* is *omitted.* A *direct* transition from unrestricted smoking to smoking bans would only be possible, if the phase of *medium* level smoking rates were extremely short, as compared to the average laps of time between two subsequent non-smoking propositions.

c) The *boundary* between feasible and non-feasible smoking policies is a *monotonously decreasing step-function* of the smoking rate S. As indicated in Fig. 4, smoking policies *below* this step-function are *feasible* and should be observable, when looking at country data. Policies *above* the mentioned line are *not feasible.* If the model proposed in Fig. 3 is empirically correct, there should be no observations in the area of Fig. 4, which is labelled as “Not feasible”. Hence the model is primarily designed for explaining the *non*-observables and much less the observables (cf. Mueller 2012: 81).

d) If *smoking rates* are *low,* propositions are *never alleviated*: In this situation the policy maker has the power to realize its preferences for strict anti-smoking laws, since according to Fig. 3, their legislation is not inhibited by the political power of the smokers.



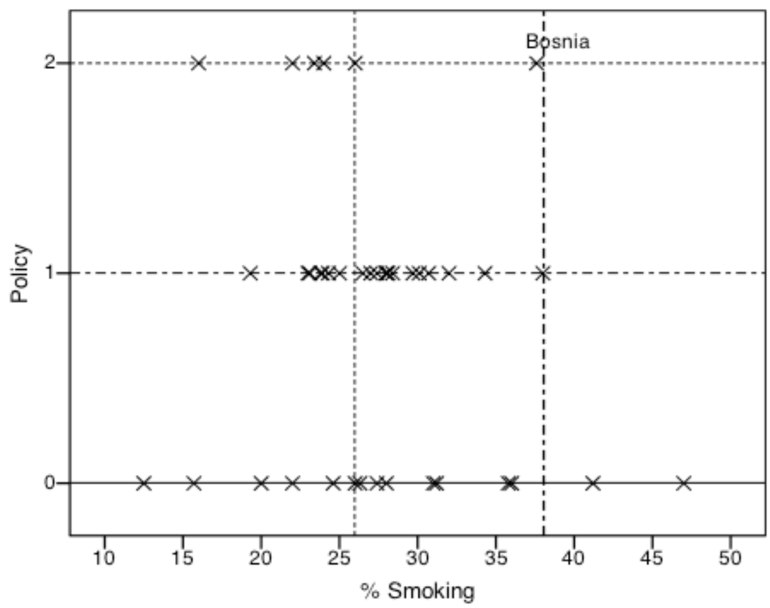
Legend: x: Feasible smoking policies for a given smoking rate S. Rest.: Smoking restrictions. e, e‘: Thresholds.

Fig. 4: Feasible and non-feasible smoking-policies: *Theoretical expectations.*

Empirical Validation

Whenever direct testing of theories is not possible, inferences from associated models are one of the possibilities to corroborate such theories by comparison with empirical data. In principle this also holds for the inferences (a) to (d), which we derived in the previous section from our Petri net model. In practice, however, the appropriate observational data are not always available. This is e.g. the case for the inferences (a) and (b) about the sequence of anti-smoking policies, which require for testing *time-series* data about the legal development of anti-smoking policies. Even more complicated is the situation with regard to inference (d), which refers to the internal processing of propositions. Since not only the *final* result, but also the *intermediate* stages are here of interest for research, only country based *case studies* of political processes offer sufficient empirical evidence for testing (d). Only inference (c) about the feasibility of smoking policies as related to the smoking rate S can be tested with the currently available data: the „European Tobacco Control Report 2007“ of WHO (2007) offers systematic country data about the share of smokers as well as the national policies with regard to smoking in restaurants, both for the period around 2005. The policy-data (WHO 2007: 40 ff., tab. 6, col. „Restaurants“) about „free“, unrestricted smoking have been recoded for this study such that they include also „voluntary agreements“, since the latter category obviously bypasses the official law making process. Regarding the share of the smokers S, we refer to the *national* definitions (WHO 2007: pp. 147 ff., annex 4, col. „Total 2002-2005“): they are more heterogeneous than the standardised definitions of WHO (2007: 143 ff.) but also more relevant for national legislators, who always have to consider their own re-election by smokers and non-smokers, when designing a new smoking policy.

In order to test the mentioned inference (c), we plotted in Fig. 5 the %-share S of smokers against the national smoking-policies for restaurants. If the hypothesis (c) were true, we should observe the data-pattern of the previous Fig. 4. This is indeed the case, if we set the thresholds e and e’ of the step-function equal to the highest values among those percentages S of Policy=1 and Policy=2, which were in our box-plot analyses *not* yet statistical outliers (Fielding and Gilbert 2000: 127). As theoretically expected, e‘=38% smokers marks the threshold, above which neither smoking-bans nor restrictions are possible (see Fig. 5, dash-dotted lines), probably because of the strength of the tobacco-lobby (Dearlove et al. 2002). Right of the other, dotted threshold indicating e=26% smokers, restrictions are possible up to e‘=38%, but smoking-bans are not feasible. There is, however one exception to this empirical regularity: *Bosnia,* which is a *statistical outlier* far right of the other observations with Policy=2 (see Fig. 5). Its statistically exceptional situation may have to do with the rather late independence of this country in 1997. It compelled Bosnia to make new laws, also with regard to tobacco consumption, which fitted to the health-oriented spirit of that time.



Legend: Policy = 0: „Free“ or „Voluntary agreement“; Policy = 1: „Restrictions“; Policy = 2: „Ban“. Sources: Policy: WHO 2007, pp. 40 ff., tab. 6, col. „Restaurants“. % Smoking: WHO 2007, pp. 147 ff., annex 4, col. „Total 2002-2005“. Sample: All countries from the WHO-region *Europe* with complete data (N=41).

Fig. 5: Feasible and non-feasible policies for smoking in restaurants: *Empirical observations* around the year 2005.

All in all, there is some evidence, that our model is empirically correct. If it were not, the whole square of Fig. 5 would be filled with randomly distributed data-points. However, it is obvious that the corroboration of inference (c) depends on a few data-points and thus has to be further validated by additional empirical evidence, at best on the basis of time series data. This new information could also be used for corroborating the inferences (a) and (b) about the sequence of anti-smoking policies, which could not be tested in this article.

Some Policy Implications

As mentioned earlier, in policy analysis models are not only used for explanatory purposes, but also for *social engineering.* In this domain, model exploration means policy *optimisation,* proof of the *feasibility* of a policy, or anticipation of its *unintended negative consequences*. Provided that the remaining part of the empirical validation succeeds, our Petri net model of smoking-bans and -restrictions may also be used for such purposes. In particular, the inferences previously gained by formal reasoning have two major policy implications:

a) If the process of health reforms for preventing passive smoking starts too *early,* it may be unfeasible. Thus, the policy making has to be coordinated with an other Petri process: the secular decline of the political power of the smokers, who at the early stage of this process could block "premature" anti-smoking laws – with detrimental effects on governmental credibility.

b) If the mentioned health reforms begin too *late,* the policy maker can be criticised for not doing enough in order to protect the general population against passive smoking. Hence, critiques of the governmental health policy could „feed" the model in Fig. 3 with artificial tokens and demonstrate that smoking-bans or -restrictions would have been feasible even long time before.

In sum: timing and sequence of policies matter and decision support from Petri net models can help to do the right thing in the right moment.

Alternative Models

In view of the importance of the share S of the smokers as an exogenous input of the previous Petri net model, one might suppose that non-linear statistical *regression* could be useful not only for estimating some of its parameters but also for replacing the whole model.

The advantage of regression models is indeed their flexibility with regard to the theories, on which they can be based on. Regression lines may e.g. represent an equilibrium derived from a balance of power theory or a maximum resulting from a rational choice approach. The common trait of most of these regression models is however a *deterministic* relation between the dependent and the independent variables, often represented by a linear or a logistic function. Unfortunately it is evident that the spatial distribution of the observations in Fig. 5 cannot be modelled by the mentioned deterministic regression lines. The proposed semi-quantitative Petri net model that distinguishes by a step-function between feasible and non-feasible policies (see Fig. 4) is obviously superior to the regression approach: whereas the *regression model* postulates that at a certain stage of development represented by the share S of smokers a certain policy-change *deterministically* occurs, the semi-quantitative *Petri net model* hypothesises that this change can only occur at an *indeterminate* moment after the mentioned stage of development has been reached.

The proposed Petri net has the additional advantage that it allows to formulate and test also hypotheses about the *sequential transformations* of tokens representing political propositions, which can hardly be modelled with conventional regression equations: one of these hypotheses, which follows from our Petri net model is the *sequence* from unrestricted to restricted and finally banned smoking in public places (see section *Some Inferences from the Model,* inferences (a) and (b)).

SUMMARY AND OUTLOOK

By this article we wanted to explore the usability of the instruments of Petri nets for a new purpose, i.e. *public policy analysis.* Since Petri nets were originally developed for purely technical problems, we had to adapt this toolkit to the needs of *social* modelling. After the introduction of time-dependent white-coloured tokens, inhibitors, triggers, transfer-priorities, and treatment-capacities, we had a modified toolkit for describing both, *qualitative* and *quantitative* aspects of *concurrent* social processes. We successfully used it for an exemplary investigation of smoking-bans and -restrictions. This example is, however, insofar incomplete as it focuses on *policy making* and the explanation of social phenomena. In spite of its intellectual relevance, it neglects the more practice-oriented aspect of the topic: *policy application,* with a strong focus on the analysis of unintended side-effects, process optimisation and the treatment-capacity of the concerned state agencies. All these aspects have not really been discussed in the previous example of *policy making.* Hence, in order to complete the demonstration of the usefulness of Petri nets for public policy analysis, additional examples from policy *application* would be desirable. Since Petri nets have been successfully used for modelling business processes (see e.g. Van der Aalst and Stahl 2011), it is likely that they will also stand this other test.

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