Transferable Development Rights (TDR) in Switzerland: Simulating a TDR Market with Agent-Based Modeling

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Summary

In Switzerland, since the 1940s the widespread and dynamic development of settlement has been perceived as a problem. There is general agreement that spatial planning instruments, which were introduced in 1979 with the first Federal Act on Spatial Planning and amended since, are inadequate to combat the unsustainable growth of land use and urban sprawl. The adoption of the recent popular initiative on second homes and the adoption of the revised federal planning law – amongst others – highlight the widespread claim for stricter legal enforcement, further regulations, and innovative instruments to tackle these problems. Among such instruments are 'transferable development rights' (TDR).

The main objective of this thesis is to propose a TDR market program for Switzerland, and to explore its possible impacts and implications. The thesis is presented as a collection of three chronologically and thematically linked scientific papers.

The first paper (chapter 2) presents a design for a TDR market in Switzerland, and based on that an agent-based model (ABM) for simulating the TDR market (TDR-ABM). The concept for the market design was defined and elaborated together with spatial planning and real estate experts and takes into account both the particular Swiss situation and experience in other countries. The TDR-ABM distinguishes three main types of agents: two agent types representing landowners who submit bids and asks (requests) for TDR, and an agent type representing a TDR exchange platform. The model simulates the trading of multiple units of TDR at fixed package sizes (TDR bundles) according to the rules of a multi-unit double auction with a uniform price.

The second paper (chapter 3) presents a questionnaire survey that was specifically designed to calibrate the TDR-ABM. A total of 1,976 spatial planning and real estate professionals – divided into four landowner categories – throughout Switzerland were contacted. Each person represented either a potential seller or potential buyer of TDR and received a questionnaire confronting her/him with a unique realistic planning situation. The approach to collect data with a participant-specific survey to directly calibrate the ABM proved successful, despite the quite low response rate (16.75%). Various results (e.g. probabilities to participate in the TDR market, regression models for TDR price (ask, bid) determination and adaptation) were calculated to be integrated into the TDR-ABM.

The third paper (chapter 4) is based on the work and findings of the previous two papers and presents the empirically calibrated agent-based model (TDR-ABM) and the detailed simulation results. The simulation was run with five different model settings which allowed an analysis of relevant political and economic questions for Switzerland. For example, it could be shown that the TDR prices were comparable with existing land prices in Switzerland, i.e. prices to develop land would not rise. In addition, it could be demonstrated that with the trade of TDR, it would be possible to downzone 11.4 km^2 of building zone land (residential zone) for which there is no demand and to develop 7.4 km^2 of new building zone land up to the year 2018 without any financial burden for public bodies. As a consequence, the defined building zone area would decrease. Finally, it could be shown that the popular initiative on second homes might only slightly reduce the building zone prices and thus had only a small effect on the TDR market price.

To sum up, this thesis presents the first agent-based model that simulates a TDR market. The simulation results demonstrated that in Switzerland the market-based instrument of transferable development rights could be a useful instrument to both reduce the building zone area and address the problem of the spatial imbalances in supply and demand for these zones. However, it should not be forgotten, that the TDR market is ‘supplementary to planning’, e.g. already the designation of the sending and receiving areas needs planning criteria.

Keywords: Transferable development rights (TDR), TDR market, Agent Based Modeling (ABM), ABM-calibration, market simulation, multi-unit double auction, participant-specific questionnaires, urban sprawl, building zones trade, undeveloped building zones, spatial imbalances of building zones

Zusammenfassung

Seit den 1940er Jahren wird in der Schweiz die ausgedehnte und dynamische Siedlungsentwicklung als Problem betrachtet. Es besteht generelle Einigkeit darüber, dass die Raumplanungsinstrumente, die im Jahre 1979 mit dem Raumplanungsgesetz eingeführt und seitdem mehrmals novelliert wurden, inadäquat für die Bekämpfung der anhaltenden Landnutzung und Zersiedelung sind. Die kürzlich angenommene Zweitwohnungsinitiative ("Schluss mit uferlosem Bau von Zweitwohnungen“) sowie die Annahme des revidierten Raumplanungsgesetzes stehen u.a. für die verbreitete Forderung nach einer strengeren rechtlichen Durchsetzung, weiteren Regulierungen sowie innovativer Instrumente zur Bewältigung dieser Probleme. Ein solches innovatives Instrument stellen “Handelbare Flächennutzungszertifikate” (FNZ) dar.

Das Hauptziel dieser Dissertation ist es, einen Vorschlag für einen FNZ-Markt für die Schweiz vorzustellen, und die dabei resultierenden Folgen und Auswirkungen zu untersuchen. Die Dissertation besteht aus drei thematisch verknüpften und chronologisch aufeinanderfolgenden wissenschaftlichen Artikeln.

Der erste Artikel (Kapitel 2) stellt ein Konzept für einen FNZ-Markt in der Schweiz vor, und auf Grundlage dessen ein agentenbasiertes Modell (ABM) zur Simulation dieses Marktes (FNZ-ABM). Das Konzept wurde zusammen mit Raumplanungs- und Immobilienexperten definiert und erarbeitet, und dies unter Berücksichtigung der speziellen Schweizer Situation sowie der Erfahrungen in anderen Ländern. Im FNZ-ABM werden drei generelle Agententypen unterschieden: Zwei Agententypen repräsentieren Landeigentümer, die Gebote (Käufer) und Offerten (Verkäufer) für FNZ abgeben, und ein Agententyp stellt die FNZ-Handelsplattform dar. Das Modell simuliert den Handel von mehreren FNZ-Einheiten zu festen Paketgrössen nach den Regeln einer Mehrgüter-Doppelauktion mit einem einheitlichen Preis.

Im zweiten Artikel (Kapitel 3) wird eine Befragung vorgestellt, die speziell für die Kalibrierung des FNZ-ABM konzipiert wurde. Es wurden gesamthaft 1‘976 Raumplanungs- und Immobilienexperten – aufgeteilt in vier Landeigentümer-Kategorien – in der ganzen Schweiz kontaktiert. Jede Person repräsentierte einen potentiellen Käufer oder einen potentiellen Verkäufer von FNZ und erhielt einen Fragebogen mit einer einzigartigen und realistischen Situationsbeschreibung. Der Ansatz, Daten mit einer Teilnehmer-spezifischen Befragung zu erheben und damit das ABM direkt zu kalibrieren, erwies sich, trotz der relativ geringen Rücklaufquote (16.75%), als zweckmässig. Es wurden verschiedene Ergebnisse (z. B. Wahrscheinlichkeiten für die Teilnahme am FNZ-Markt, Regressionsmodelle für die Bestimmung und Anpassung des FNZ-Preises (Offerten, Gebote)) für die Integration ins FNZ-ABM berechnet.

Der dritte Artikel (Kapitel 4) basiert auf den Arbeiten und Ergebnissen der vorherigen zwei Kapiteln und stellt das empirisch kalibrierte agentenbasierte Modell (FNZ-ABM), sowie die detaillierten Simulationsresultate vor. Um politisch und ökonomisch relevante Fragen für die Schweiz zu analysieren, wurden bei den Simulationsdurchläufen fünf verschiedene Modell-Einstellungen unterschieden. So konnte beispielsweise gezeigt werden, dass die FNZ-Preise mit bestehenden Landpreisen in der Schweiz vergleichbar sind, d.h. die Preise fürs Bebauen von Land würden nicht steigen. Darüber hinaus konnte dargelegt werden, dass durch den Handel von FNZ bis ins Jahr 2018 11.4 km^2 nicht-nachgefragtes Bauland (Wohnzone) ausgezont sowie 7.4 km^2 neues Bauland entwickelt werden könnte. Als Folge davon würde die absolute Bauzonenfläche verringert werden. Schliesslich konnte gezeigt werden, dass die Zweitwohnungsinitiative lediglich einen geringfügigen negativen Einfluss auf die Bauzonenpreise haben wird und dass die Effekte auf den FNZ-Marktpreis demzufolge gering wären.

Die vorliegende Arbeit stellt das erste agentenbasierte Modell vor, das einen Markt für FNZ simuliert. Die Simulationsergebnisse konnten darlegen, dass das marktbasierte Instrument der handelbaren Flächennutzungszertifikate ein nützliches Instrument sowohl für die Reduktion der Bauzonenfläche als auch zur Entschärfung des Problems der räumlichen Ungleichheiten im Angebot und der Nachfrage nach Bauzonen sein kann. Es sollte jedoch beachtet werden, dass FNZ als Ergänzung bisheriger Raumplanungsinstrumente zu verstehen sind, z.B. sollte das Ausweisen von Sender- und Empfängergebieten nach Planungskriterien erfolgen.

Schlagworte: Handelbare Flächennutzungszertifikate (FNZ), FNZ-Markt, Agentenbasierte Modellierung (ABM), ABM-Kalibrierung, Marktsimulation, Mehrgüter-Doppelauktion, Teilnehmer-spezifische Befragung, Zersiedelung, Handel mit Bauzonen, unüberbaute Bauzonen, räumliche Disparitäten von Bauzonen

Résumé

Depuis les années 1940, le développement urbain, étendu et dynamique, est jugé problématique en Suisse. Il est généralement admis que les instruments d’aménagement du territoire, introduits en 1979 avec la loi sur l’aménagement du territoire, et modifiés à plusieurs reprises depuis lors, ne sont pas adaptés à la lutte contre l’utilisation croissante des sols et la progression de l’étalement urbain. L’initiative sur les résidences secondaires acceptée récemment ("Pour en finir avec les constructions envahissantes de résidences secondaires“), ainsi que l’acceptation de la révision de la loi sur l’aménagement du territoire, reflètent entre autres des exigences croissantes: celle d’une application plus stricte de la législation en vigueur, celle aussi de réglementations supplémentaires et d’instruments novateurs à même de résoudre ces problèmes. Les “certificats d’utilisation du sol négociables” (CUS) sont l’un de ces instruments.

Proposer un marché de CUS pour la Suisse et en rechercher les répercussions et implications possibles constitue l’objectif principal de cette thèse. Celle-ci se compose de trois articles thématiquement liés qui se suivent chronologiquement.

Le premier article (chapitre 2) présente le concept mis au point pour un marché de CUS en Suisse et, à partir de celui-ci, un modèle à base d’agents (ABM) visant à simuler ce marché (CUS-ABM). Ce concept a été défini et élaboré de concert avec des experts en aménagement du territoire et en immobilier. Il prend en considération la situation spécifique de la Suisse, de même que les expériences d’autres pays. Le CUS-ABM distingue trois principaux types d’agents: les propriétaires de terrain qui participent aux enchères (acheteurs) et soumettent des offres (vendeurs) pour des CUS constituent les deux premiers, la plate-forme de négoce des CUS représentant le troisième type d’agents. Le modèle simule le négoce de plusieurs unités de CUS relevant de paquets de tailles fixes selon les règles d’une double vente aux enchères multi-unités avec un prix uniforme.

Le deuxième article (chapitre 3) présente une enquête par questionnaire spécialement conçu pour l’étalonnage du CUS-ABM. Pour toute la Suisse, 1996 experts en aménagement du territoire et en immobilier – répartis en quatre catégories de propriétaires de terrain – furent contactés. Chacun d’eux figurait un acheteur ou vendeur potentiel de CUS et reçut un questionnaire avec une description unique et réaliste de la situation. Cette démarche qui consiste à collecter des données au moyen d’une enquête spécifique aux participants, et ainsi à étalonner directement l’ABM, a fait ses preuves, et ce malgré le taux de réponse relativement faible (16.75 %). Différents paramètres ont été estimés en vue de leur intégration dans le CUS-ABM: probabilités de participer au marché de CUS, modèles de régression pour la fixation et l'adaptation du prix des CUS (offres, enchères) notamment.

Le troisième article (chapitre 4) se fonde sur les travaux et les résultats des deux chapitres précédents et expose le modèle à base d'agents étalonné empiriquement (CUS-ABM), ainsi que les résultats détaillés des simulations. Celles-ci s'appuient sur cinq paramètres de modélisation différents afin de favoriser l'analyse, pour la Suisse, de questions pertinentes d'ordre économique et politique. Il fut ainsi possible de montrer entre autres que les prix des CUS étaient comparables aux prix fonciers prévalant dans le pays, ce qui signifie que les prix pour l'aménagement de surfaces à bâtir n'augmenteraient pas. On put aussi mettre en évidence le fait que le négoce de CUS permettrait, d'ici à 2018, de classer hors zone à bâtir une surface de 11.4 km^2 de terrain pour laquelle aucune demande n'existe (zone résidentielle) et d'aménager 7.4 km^2 de nouveaux terrains à bâtir. Avec pour conséquence la réduction de la surface absolue de zones à bâtir. Il fut enfin possible de souligner que l'initiative sur les résidences secondaires n'aurait qu'un effet négatif restreint sur les prix des zones à bâtir, et que l'impact sur le prix de marché des CUS serait de ce fait limité.

Cette thèse présente ainsi le premier modèle à base d'agents qui simule un marché pour les CUS. Les résultats des simulations démontrent que l'instrument des certificats d'utilisation du sol négociables, instrument basé sur le marché, peut s'avérer utile non seulement pour réduire la surface de la zone à bâtir, mais aussi pour remédier au problème du déséquilibre spatial entre l'offre et la demande des zones à bâtir. Il faut toutefois ne voir dans les CUS que des compléments aux instruments d'aménagement du territoire existants; la délimitation des zones émettrices et réceptrices doit par exemple avoir lieu conformément aux critères de planification.

Mots-clés: Certificats d'utilisation du sol négociables (CUS), marché de CUS, modélisation à base d'agents (ABM), étalonnage ABM, simulation du marché, double vente aux enchères multi-unités, questionnaires spécifiques aux participants, étalement urbain, échange de zones à bâtir, zones à bâtir non construites, disparités spatiales des zones à bâtir

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1 Introduction

The Swiss population is concerned about the development of its landscape. This is not only highlighted by the success of the recently adopted ‘popular initiative on second homes’ (adopted on 11 March 2012) and the adopted revision of the federal planning law (adopted on 3 March 2013). A recently conducted representative survey[2] among the Swiss population has shown that a large number (65%) of the respondents would approve limiting the settlement area to the present amount. Indeed 80% of the respondents would like to restrict development activities in particularly beautiful landscapes. These high levels are not a coincidence; the survey has been conducted annually since 2006 and has shown consistently similar results.

The concern of the population is supported by the most recent results of the Swiss land use statistics (German: “Arealstatistik”, French: “statistique de la superficie”): The settlement area increased by 23.5%[3] between the monitoring periods 1979/85 and 2004/09. Regarding the settlement area in relation to the population, in 1979/85 each person required 375 sqm, while in 2004/09 the settlement area per person increased to 395 sqm. Yet, the Swiss Government claimed in the ‘Sustainable Development Strategy 2012-2015‘[4] that the settlement area should be stabilized at 400 sqm per capita. Hence, if the present trend of land development continues, it is highly doubtful whether this claimed stabilization will be achieved. In addition, the population is predicted (medium scenario) to grow from the current 8 million to 9 million by 2055 (SFSO, 2010c).

The expansion of the settlement area has mostly occurred on the Swiss Plateau with a corresponding loss of farmland as a result (IRL, 2003; SFSO, 2010a). The expansion is mainly related to economic growth and changes in lifestyle. Economic growth has led to an expansion of various areas, including residential, industrial, commercial and traffic areas (SFSO, 2010b). Moreover, in peripheral areas, location marketing additionally stimulates the land use (Avenir Suisse, 2012). Changes in lifestyle, for example, have led to significantly more one-person households and single-family housing (IRL, 2003), and a greater demand for living space per person. It has been shown that in particular urban sprawl, i.e. development outside high-density areas, has many negative consequences for the environ-

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[2] The survey was conducted between 22 February and 5 March 2012 by the research institute „gfs-zürich“, on behalf of Pro Natura. For more information see: http://www.pronatura.ch/landschaften or http://www.gfs-zh.ch, accessed: 11-27-2012.

[3] Results of the Areal Statistics 1979/85 – 2004/09 (http://www.bfs.admin.ch/bfs/portal/de/index/themen/02/03.html, accessed: 2012-11-02). In the results of the year 2004/2009, the Canton of Graubünden has not yet been included.

[4] For more information see: www.are.admin.ch/themen/nachhaltig/00262/00528, accessed: 11-27-2012.

ment, causes higher infrastructure costs, and leads to greater energy consumption (Baumgartner, 2005; Brownstone and Golob, 2009; Ewing, 2008).

The described land-use problem is reinforced by the location of the building zones (Germ.: “Bauzonen”; French: “zones à bâtir”). According to ARE (2008) and Fahrländer Partner (2008), between 38,000 and 53,000 hectares (17% to 24%) of the building zone areas have not yet been developed, and more importantly, there is a severe spatial imbalance in supply and demand for undeveloped building zones. In urban areas the expected demand for the next twenty years exceeds the supply (current reserves on building zone land), yet in areas far away from the centers the supply exceeds the demand. In addition, only 30% of the building zones (both developed and undeveloped) are well or very well connected with public transport and almost half of the building zones are not or only marginally connected. The building zones in major centers are significantly better connected with the public transport network than areas that are largely agricultural and/or used for tourism (ARE, 2008).

The concern of the population and the need for new policies and innovative methods to reduce the land use problems have been recognized by the Swiss Confederation. On 3 March 2013 the Swiss population has accepted the revision of the Federal Act of 22 June 1979 on Spatial Planning. This revision includes, among other things, measures for the mobilization of hoarded building zone land in suitable areas according to Swiss spatial planning principles, the introduction of a nationwide tax on planning gains (German: “Mehrwertabgabe”, French: ”Prélèvement de la plus-value”), and, the obligation of downzoning[5] too large building zones for which there is no predicted demand in the next 15 years. According to Swiss law downzoning the status of building zones to agricultural land for instance, in general means expropriating the owner (material expropriation), who would then have to be fully compensated[6].

From a spatial planning perspective, the revision is decidedly desirable, however, for many municipalities (e.g. municipalities in the canton of Valais or Vaud, cf. BSS, 2011), the compensation of the landowners will be almost impossible to finance. Therefore, it is doubtful whether the measures of the revision of the Federal Act can be put into practice.

A possible or additional solution to reduce the above-mentioned land-use problems are transferable development rights (TDR). TDR are a market-based instrument which allows transferring development rights. The result of such transfers may be seen as a form of rezoning. In a TDR market, landowners in so-called 'sending areas' can sell their right to build on a parcel of land, to landowners in 'receiving areas'. This results in less land consumption in the former and increased density in the latter,

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[5] The practice of reducing the zoning of land from building to agricultural zone.

[6] For more information about recent judgments of the Swiss Federal Supreme Court concerning material expropriation see e.g., VLP-ASPAN (2011, 2012). For a deeper judicial explanation see Häfelin et. al. (2010).

since in the receiving area there might be denser development compared to the ordinary density in the sending area.

The sending area comprises undeveloped building zone parcels, which are not in demand and/or which should be downzoned according to Swiss spatial planning principles. The receiving area consists of parcels not yet designated as building zones, which – in line with and respecting the Swiss spatial planning principles – should be developed in the future because of high demand.

In Switzerland, TDR programs have not yet been brought to practice, and only a few conceptual studies (cf. ARE, 2006; Gmünder, 2004, 2010; Süess and Gmünder, 2005; Zollinger and Seidl, 2005; Zollinger, 2006) have been conducted. In these studies, some authors even worked with the unjustified assumption that TDR could be used for increasing the building density on already developed building zone parcels. This is hardly possible, because the lawful allowable gross floor (living) area is often not used and therefore, in such situations, no TDRs would be demanded. In addition, no study has examined what the needed trading area would be to have a 'balance' in the supply and demand of TDRs. Overall, the main disadvantage of the studies on TDR conducted so far is that no simulations have been done, but merely simple calculations. They lack specifying details, such as the trading mechanism (e.g. bilateral trading, auction etc.), and no land-related data (e.g. cadastral data) have been used to test the feasibility of their proposals.

Currently, none of the proposals would be suitable for a practical implementation in Switzerland. None examines the influence of primary allocation mechanisms or of trading mechanisms on the demand and supply of TDR, although trading mechanisms play a central role in TDR programs (cf. Kopits et al., 2005). Due to this lack of theoretical and empirical investigation, knowledge about TDR and the implications of their application is limited. Meanwhile, TDR are being controversially discussed by politicians, spatial planners, environmental organizations, landowner lobbies, and scientists, while also attracting considerable public interest (e.g. ARE, 2006; NZZ, 2007a, 2007b; Schläpfer, 2007; Süess & Gmünder, 2005; Zollinger, 2006).

This thesis aims to fill these identified research gaps. This will be done by drawing on both different disciplines and knowledge of local stakeholders and spatial planners, and by linking and further developing these bodies of knowledge. The aim is to develop an empirically calibrated agent-based simulation for a TDR market, which – to my knowledge – is the first one developed. Therewith, the thesis may also contribute to the discussion of the TDRs' suitability towards a sustainable development of settlements in Switzerland or any comparable country.

1.1 Objectives and main steps of the thesis

The objective of this thesis is to propose a TDR market program for Switzerland, and to explore its possible implications and impacts. The research process covered the following four main steps (cf. also Fig. 1-1):

1) creating a theoretically sound concept of a TDR market program for Switzerland (incl. auction and TDR market design);
2) building a suitable agent-based simulation model for a TDR market (TDR-ABM);
3) designing and realizing of a survey among spatial planning and real estate experts, and analyzing the survey data to be used for calibrating the TDR-ABM;
4) running the agent-based simulation and discussing the simulation results.

The results are summarized as recommendations for a potential implementation of such a program in Switzerland and thereby contributing to the public, and expert debates.

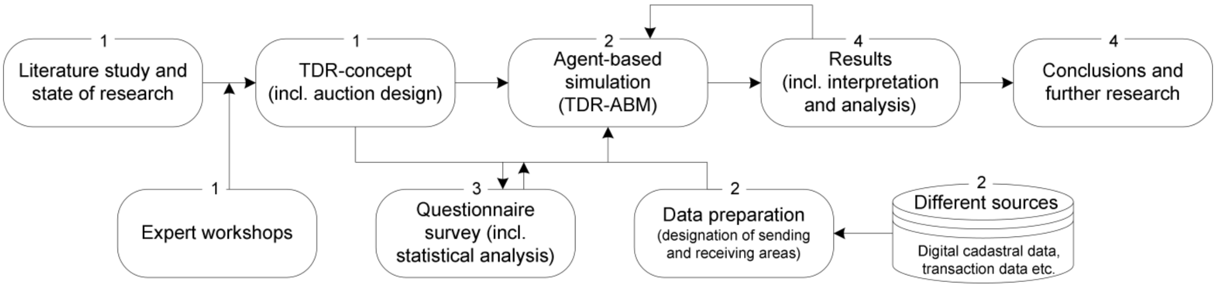

Fig. 1-1: Main steps of the PhD-thesis (the numbers show the working step).

1.2 Structure and content of the thesis

The thesis is presented as a collection of three papers, which offers the possibility to consider each paper (chapter) independently. At the same time, the order of the papers logically follows the research process and progress, and hence each builds upon the other. The publication status is as follows: Paper 1 has been submitted to the *Journal of Artificial Societies and Social Simulation* and is currently ‘under review’. Paper 2 has been submitted to the *Journal of Environmental Policy & Planning* and is currently ‘under review’. Paper 3 has been submitted to the Journal *Environment and Planning B: Planning and Design* and is currently ‘under review’.

The **first paper** of the thesis, titled “TDR market concept and agent-based model” (chapter 2), presents both a TDR market concept for Switzerland and an agent-based model (ABM) for simulating the proposed TDR market (*steps 1 and 2*). The definition and elaboration of the presented market concept included a literature research of such programs, the investigation of relevant judicial and spatial situation in Switzerland, as well as two expert workshops. One of the workshops was with spatial planning and real estate experts[7] and one with auction design specialists[8].

Based on the developed TDR market concept, the paper also presents an agent-based model for simulating the TDR market (TDR-ABM). The advantage of an agent-based model – compared to e.g., a pure analytical method – is that it is possible to model individual decision-making and human behavior (e.g. the degree of rationality, risk aversion, learning abilities etc.) which is essential to reflect the participation of heterogeneous participants in the TDR market.

The TDR-ABM[9] distinguishes three general agent-types. Two agent-types represent landowners who can submit asks (sender agents) and bids (receiver agents) for TDR. The behavior of these agents depends on the landowner category (e.g. enterprises, private persons etc.), though, in the first paper the behavior of the agents is not yet calibrated with empirical data (empirical calibration follows in paper 3). The third agent-type stands for the TDR exchange platform. This agent is responsible for the communication between the supply (sender agents) and demand (receiver agents) side of the market, and calculates the market clearing price according to the rules of a multi-unit (fixed TDR bundles) double auction with a uniform price.

The performance of the developed model was tested with empirical data which was derived from existing studies on supply (cf. ARE, 2008) and future demand (cf. Fahrländer Partner, 2008) for building zones. Moreover, the same data were also used for a sensitivity analysis of selected parameters (probability to participate in the TDR market). However, in this first paper, the behavior (e.g. price determination and adaptation) of the agents was not calibrated with empirical data.

The **second paper** (chapter 3) titled “A survey of market participants to inform the TDR-ABM” presents the results of a questionnaire survey (mail and web based) for calibrating the TDR-ABM (*step 3*). The survey was conducted to gather data for the calibration of the TDR-ABM. No other data were available to draw on.

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[7] The workshop took place at ETH Zurich on 18 March 2010. Participants were experts from local authorities (Confederation/Canton/Municipality), banks, real estate companies, a planning association and academics.

[8] The auction design for the proposed TDR market has been elaborated in a small workshop at Karlsruhe Institute of Technology (KIT) on 30 September 2010. The auction design experts were: Prof. Stefan Seifert and Dr. Jens Müller (KIT).

[9] The simulation has been programmed in Java with use of the free, and open source agent-based modeling and simulation platform Repast Simphony (http://repast.sourceforge.net, accessed: 2011-09-15).

Because of the complex topic of transferable development rights and the lack of any public information and debate about this instrument, it was decided to contact persons qualified in the field of spatial planning and real estate (called ‘professionals’ in what follows), instead of a random sample of all existing and potential landowners. Among the contacted persons four different landowner categories (e.g. enterprises, non-profit institutions, representatives of private persons, cooperatives) were distinguished, and each person addressed with a questionnaire represented either a potential seller or potential buyer of TDR. A special approach for this survey was that each single questionnaire stated a unique realistic situation description that suited the contacted landowner category. The numbers and details (e.g. parcel area, location etc.) for these descriptions were derived from existing land registry data and transaction data of undeveloped land parcels (building and agricultural zones).

In order to obtain realistic and reliable data to inform the TDR-ABM, a plausibility test based on the theoretical TDR value was performed. These data were then analyzed with descriptive and analytical statistical methods in order to generate the parameters for the direct calibration of the TDR-ABM.

The **third paper** (chapter 4), titled “Results of the TDR market simulation” (*step 4*) presents the empirically calibrated agent-based model (TDR-ABM) and the detailed simulation results. This paper is based on the work and findings of the other two papers (chapters 2 and 3), and as it discusses the application of the proposed TDR market, it is the most interesting paper.

To get valuable economic and political results, five different model settings were simulated. This allowed a number of economic values to be examined. It enabled showing the potential TDR supply and demand, the traded TDR quantity, as well as the TDR prices and overall financial volume under the different model settings. Moreover, it was – among other variants/issues – possible to investigate the impact of uncertainties, e.g., the uncertainties in the estimation of the participation probability parameters.

As TDR trading period it was chosen to analyze the period 2013-2018 (end of 2017). No longer periods of time were analyzed due to potentially significant and unpredictable socio-economic changes (e.g. population growth) in the future.

In order to validate the simulation results, the obtained TDR prices were compared with current land prices. Moreover, it was analyzed how much land could be downzoned in the sending area, respectively developed in the receiving area. By comparing these areas, it was possible to investigate the development (increase, decrease) of the absolute building zone area in Switzerland, as well as in the canton of Valais.

On the basis of the findings of the three papers, chapter 5 provides **general conclusions**, proposes ideas for **further research,** and summarizes **general recommendations** and **factors of success** for a potential implementation of a TDR market in Switzerland.

2 TDR market concept and agent-based model[*]

Abstract: In Switzerland, since the 1940s the development of settlement has been perceived as an important problem in geospatial planning. There is general agreement that current spatial planning instruments are inadequate to combat the unsustainable growth of land use and urban sprawl. A recent public initiative (‘landscape initiative’) and the plan to revise the federal planning law also highlight the need for regulations and innovative instruments to tackle these problems. Among such instruments are 'transferable development rights' (TDR).

The aim of this paper is to present both a TDR market design for Switzerland and an agent-based model (ABM) for simulating the proposed TDR market. We distinguish three types of agents in our model: two agent types representing landowners who submit bids and asks (requests) for TDR, and an agent type representing a TDR exchange platform. The ABM simulates the trading of multiple units of TDR at fixed package sizes (TDR bundles) according to the rules of a multi-unit double auction with a uniform price.

In order to evaluate the performance of the developed model and the sensitivity of selected parameters, we tested it with empirical data from Switzerland. The results of a performance analysis show that the model works well with a high number of agents and the sensitivity analysis show that the resulting prices do not over- or undershoot, even with low participation rates.

Keywords: Transferable development rights (TDR), TDR market, Agent Based Modeling (ABM), market simulation, multi-unit double auction, market clearing price

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[*] This chapter is a slightly amended version of the paper “Simulating a market for transferable development rights (TDR) with agent-based modeling” written by Gianluca Menghini, Fabian Gemperle and Irmi Seidl. The paper has been submitted to the *Journal of Artificial Societies and Social Simulation* and is currently ‘under review’. The authors would like to thank the Swiss National Science Foundation for funding the project (K-21K1-1224), Wüest und Partner AG, the Cantons of Zurich, Thurgau and Fribourg for providing various data sets on building and agricultural land, and Veronika Killer from the Institute for Transport Planning and Systems (IVT) at ETH Zurich for the assistance in data preparation. Moreover, we thank Prof. K.W. Axhausen, also from IVT at ETH Zurich for his valuable comments on an earlier version of this paper.

2.1 Introduction

In Switzerland, between 1979 and 2009 the settlement area has increased by 23.5%[10]. Most of the expansion occurs in the form of urban sprawl and takes place on the Swiss Plateau, where it has resulted in a large loss of farmland (IRL 2003). This expansion is mainly due to economic growth and changes in lifestyle. It has been shown that urban sprawl has negative consequences in at least three areas: for the environment, infrastructure costs, and energy consumption (Baumgartner 2005; Brownstone and Golob 2009; Ewing 2008).

Particularly problematic is the extent of the building zones: of the approximately 227,000 hectares (developed and undeveloped; cf. Fig. 2-1), 38,000 to 53,000 hectares (17 to 24%) have in fact not been developed (ARE 2008). These undeveloped building zone areas that are mostly located in working and residential areas could provide space for about two million additional inhabitants according to Fahrländer Partner (2008) and ARE (2005). Switzerland has a present population of approximately 8 million inhabitants.

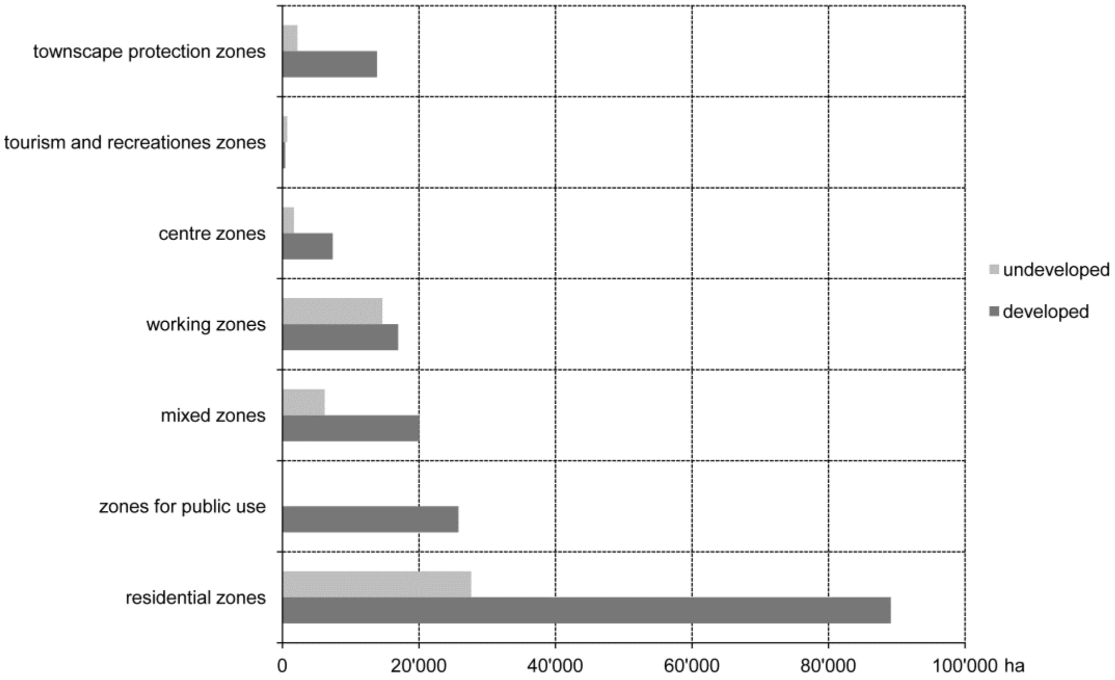

Fig. 2-1: Situation of the building zones in Switzerland (own figure, data: ARE, 2008).

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[10] Results of the Areal Statistics 1979/85 – 2004/09 (http://www.bfs.admin.ch/bfs/portal/de/index/themen/02/03.html, accessed: 2012-11-02). In the results of the year 2004/2009, the Canton of Graubünden has not yet been included.

Besides their extent, the location of these undeveloped zones is a problem. As Fig. 2-2 shows, there are significant differences in supply and demand for these zones, with high demand in the major centers and along major transport routes, which is expected to significantly exceed the current reserves. At the same time, municipalities far away from the centers dispose of areas of undeveloped building zones that significantly exceed the expected demand for the next twenty years. Another problematic aspect is that only 30% of the building zones (both developed and undeveloped) are well connected to public transport (ARE 2008).

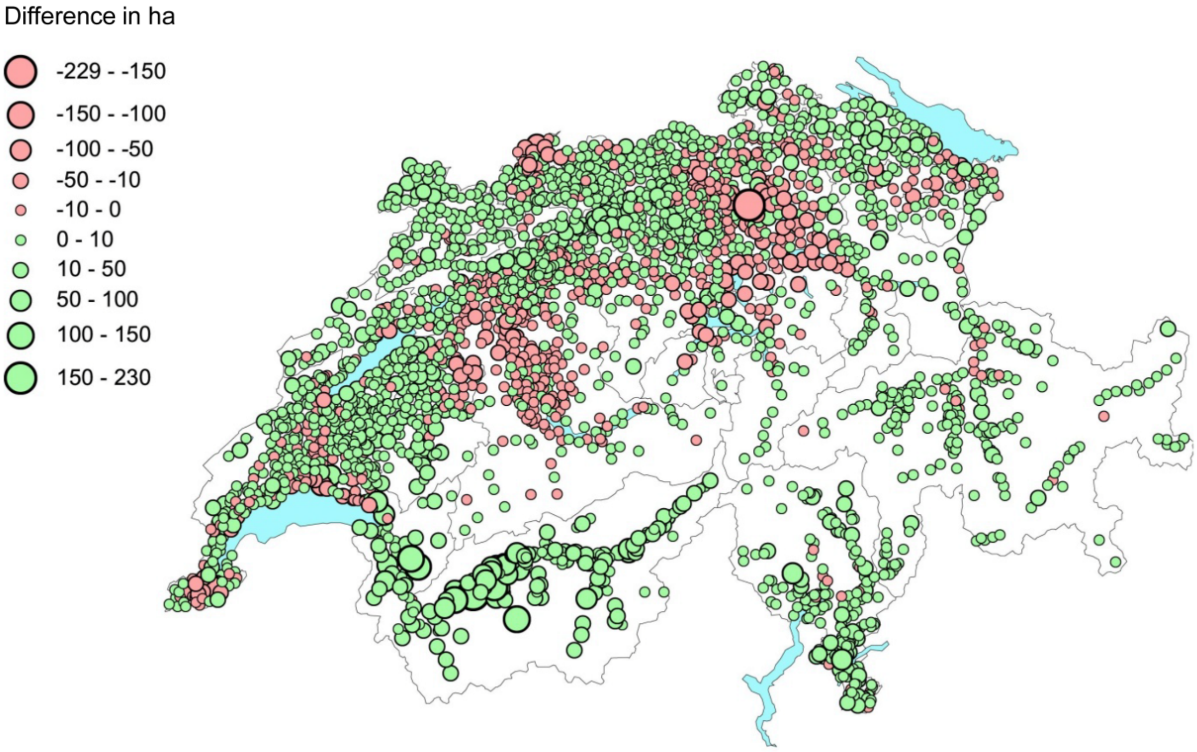

Fig. 2-2: Location and size of undeveloped building zones (green) and future demand of building zones (residential zones) (red) for 2005 – 2030 as modeled by Fahrländer Partner (2008).

The major reasons for the large building zones are twofold: first, in Switzerland each of the approximately 2,500 municipalities has the right to designate the building zones within its area. The incentive to increase the area of these zones is strong as new settlements promise new tax revenues. Second, the Swiss Federal Act of 22 June 1979 on Spatial Planning has not been followed as it requires that undeveloped building zones should not be greater than the anticipated demand for the next 15 years (Art. 15) (ARE, 2006; Gmünder, 2004).

The high rate of land usage and the extent of still undeveloped building zones clearly goes against the principles for economical land use as specified in Art. 1 of the Swiss Federal Act of 22 June 1979 on Spatial Planning. Hence, there is general agreement that the current spatial planning instruments are insufficient and that innovative methods to reduce land usage and urban sprawl are needed (ARE, 2006; Süess and Gmünder, 2005; Zollinger, 2006). Various incentive-based tools are currently being discussed (cf. e.g. Gmünder 2004, 2010) of which ‘transferable development rights’ (TDR) appear quite promising, given the problems to be solved.

The TDR instrument is not well-known in Switzerland and there is little political willingness to implement such an instrument without research proving its worth, both in how it functions and the effects it has (Gmünder, 2010). A simulation based on a reflected TDR program for Switzerland and exploring the possible impacts can provide very useful information and inform the political discussion about TDR implementation in Switzerland.

Spatial modeling and simulation have recently become standard approaches in land-use change research (cf. e.g. Lesschen et al., 2005; Parker et al., 2002; Torrens, 2010). However, the modelers have generally not considered the human behavioral component when establishing their models. As a result, these models do not clarify the human component resulting only in the identification of land development patterns rather than suggesting guidelines for political measures. Both aspects - individual decision-making and human behavior - are considered in agent-based models. Hence, this kind of model is suitable for modeling a TDR market.

In the first section of this chapter we briefly explain the concept of Transferable Development Rights (TDR). We describe where and how TDR have been used so far and how they could be used in Switzerland[11]. We then discuss agent-based modeling concepts and in particular agent-based land-use models. Next, we illustrate the details of the proposed agent-based model for simulating a TDR market in Switzerland. In order to evaluate the model, we present results of a performance and sensitivity analysis with selected empirical data and parameters. We conclude with a discussion of the proposed TDR market and the corresponding agent-based model, with a summary of the most important findings and suggestions for future work.

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[11] However, it is not the aim of the paper to explain the advantages and disadvantages of a TDR program. Information about TDR programs can be found e.g. in Kaplowitz et al. (2008) or Pruetz (2003). More information on spatial planning in Switzerland can be found in VLP-ASPAN (n.s.).

2.2 TDR: application, markets and modeling

2.2.1 Definition and the basic concept of TDR

Definition

Transferable development rights (TDR)[12] are a quantity-controlling, economic instrument based on the concept of tradable usable resources (or emissions). Overall, environmental economic instruments can be divided into two kinds: fiscal (taxes, fees) and quantity-control (tradable permits, rights, quotas). The latter aims to reduce the environmental impact by only allowing a pre-determined amount of usable resources (or emissions, land etc.). The price of the permits depends on supply and demand in the corresponding market.

Another basis of TDR is the bundle-of-rights theory, which maintains that ownership of a parcel of real estate may entail many different rights, including the right to its occupancy and use, the right to sell it in whole or in part, or the right to transfer it by contract for specified periods of time (Mann and Barber, 2007). These rights, subject to government limitations and private restrictions, can be sold, leased, transferred, or otherwise disposed of individually.

Basic TDR concept

A TDR program can be designed as a so-called single-zone or dual-zone program. In a single-zone program, anyone within the program area can - after the initial allocation - buy or sell rights. In contrast, in a dual-zone program, both sending and receiving zones are defined. Rights/permits can be sold from the sending zone and bought within the receiving zone (Chomitz, 2004; Johnston and Madison, 1997).

A possible TDR dual-zone program is illustrated in Fig. 2-3. Landowners in so-called ‘sending areas’ (here: municipality A) can sell their rights to develop a parcel to landowners in ‘receiving areas’ (here: municipality B). The former are areas in which development is not demanded or should be prevented; the latter are areas in which development is desired. The TDR market price represents a compensation for the loss of benefits (being able to develop) caused by the downzoning (reducing the zoning of land from building to agricultural zone) of parcels in the sending area. TDR trade may be managed by ‘credit banks’, which act as buying and selling mediators and provide market platforms (Kopits et al., 2005).

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[12] In the scientific literature also known as ‘Tradable Development Rights’, ‘Transferable Development Credits’ (TDC) or ‘Transferable Title Rights’ (TTR) (Pruetz, 2003).

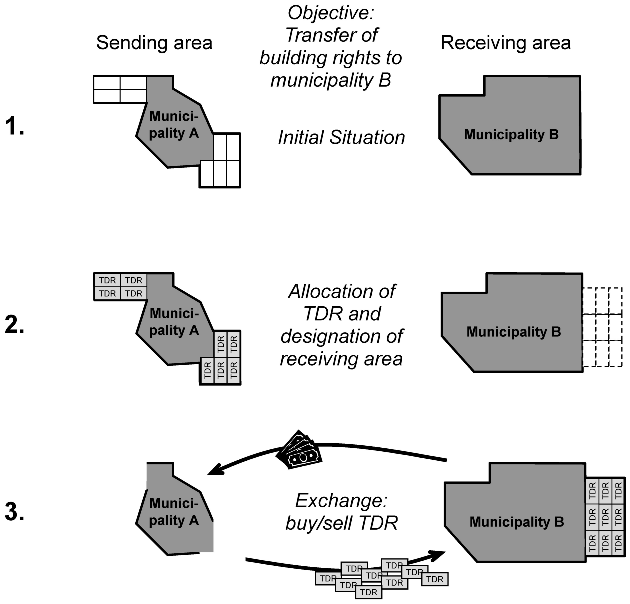

Fig. 2-3: The concept of transferable development rights (TDR); Gmünder (2010), modified figure.

2.2.2 TDR programs in various countries

The application of transferable development rights is widespread in the United States. According to Pruetz (2003), in early 2000, there were 142 TDR programs of all sizes in 32 different States. The goals of these programs range from the conservation of agricultural land, the protection of ecologically valuable regions to the limitation of the heights of buildings or the preservation of sites of historic interest in urban areas.

TDR programs can be designed to involve compulsory or voluntarily participation. The programs in the USA have shown that compulsory programs tend to be more successful in reaching the stated objectives. However, the voluntary programs had fewer problems gaining political acceptance (Johnston and Madison, 1997).

The most successful program in the USA is in Montgomery County, Maryland (Janssen-Jansen et al., 2008; Kopits et al., 2005; Pruetz, 2003). The main goal of the program was to preserve Montgomery County’s primary rural character and farmland, and 110,000 acres were designated as a ‘sending area’ for that purpose. This area, called the Agricultural Reserve, makes up more than one third of the County’s total land area. The farmers in the Reserve were able to sell TDR as compensation for discontinuing some potential development. Likewise, a ‘receiving area’ with higher development potential was identified. The landowners in this area could increase the original development potential by purchasing TDR. As a result, 17,000 acres of cultivated and uncultivated land was saved and received long term protection. Yet, not all TDR programs have been as successful as the one in Maryland (Kopits et al., 2005; Pruetz, 2003). There are five possible reasons for some programs failing: voluntary participation (no obligation), not enough demand in the receiving area, lack of a TDR bank guaranteeing transparency, mismanagement of the program, and insufficient knowledge of the land market while designing the program (Machemer and Kaplowitz, 2002).

Outside the USA, TDR programs have been designed and partly applied in Australia, Canada, France, Germany, India, Italy, Japan, Latin America, the Netherlands, South Korea, Spain and New Zealand. Yet, the instrument is still not very widespread in these countries and it has been used for a range of purposes: in cities to increase the building density and to protect monuments; in rural areas to control land use, to compensate reduced development possibilities, and to preserve natural areas (Chomitz, 2004; de Kam and Lubach, 2007; Gibson, 1996; Henger and Bizer, 2010; Janssen-Jansen, 2008; Kaplowitz et al., 2008; Micelli, 2002; Radermacher et al., 2004; Renard, 1999).

2.2.3 Proposal: TDR market design for Switzerland

This section shows what a TDR market design for Switzerland could look like and how data for its implementation and modeling could be prepared.

Swiss peculiarities to be considered in a TDR market

TDR programs originally devised for the US or other countries are not applicable because in Switzerland there are a specific spatial planning system and situations resulting from that. One peculiarity is the existence of large, still undeveloped building zones, most of which could be developed immediately (ARE, 2008). However, these zones typically lie in regions with no or little demand for development (cf. Fig. 2-2). According to Swiss law downzoning the status of such building zones into agricultural land for instance, would mean expropriating the owner, who would then have to be fully compensated. Hardly any municipality in Switzerland would have the financial means to do this.

Another peculiarity is that landowners typically do not achieve the development density permitted by law. For example, in the Canton of Zurich, it is only 66% of the currently permitted gross floor area (Kanton Zürich, 2009). Thus, there is potential to build much more densely, and increasing density to the legal limit would not require TDR programs.

These specifically Swiss features suggest that TDR could be applied to allow for an exchange of existing reserves with areas where there is a high demand for building zones. Such an exchange would prevent designating new additional building zones. Consequently, with the support of spatial planning and real estate experts[13] we recommend implementing the TDR instrument as a dual-zone program, specifying both a ‘sending’ and a ‘receiving area’, and capping the existing building zones (following the cap-and-trade principle).

Note that the TDR described here involve trading a development opportunity (construction right), which can be transferred from one parcel of land to another. Before doing so, the sending and receiving areas have to be designated. In contrast, tradable planning permits (TPP), e.g. in Germany, involve trading permits to designate new building zones. Municipalities have to buy TPP, allocated by the planning authority, in order to be able to designate new building zones (Henger and Bizer, 2010; Seidl et al., 2009).

The aim of a Swiss TDR program is to sell as many TDR as possible and to have land costs that are close to the existing costs (prices) for building land (before TDR introduction).

Characteristics of the sending and receiving area

The sending area consists of undeveloped building zone parcels, which can then be downzoned in accordance with existing Swiss spatial planning principles. Parcels in sending areas are characterized by the following characteristics. They are:

- without or with only limited infrastructure (e.g. streets, electricity, water);
- without good public transport connections;
- close to protected natural areas;
- parcels that spatially separate two or more nearby conservation areas.

The receiving area consists of land parcels not designated as building zones, which, however should be developed in the future, in accordance with Swiss spatial planning principles. Parcels in the receiving area have one or more of the following characteristics. They are:

- adjacent to existing building zones;
- unbuilt sections between settled areas, provided they are not yet building zones;
- parcels that can be easily provided with infrastructure (e.g. streets, electricity, water) at low cost;
- parcels with good or potentially easily established public transport connections.

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[13] The TDR concept was presented and discussed at an expert workshop in Zurich (ETH Zurich) on March 18, 2010. The goal of the workshop was to present the concept to experts (local authorities (Confederation/Canton/Municipality), banks, real estate companies etc.) and to implement their ideas and suggestions.

Designating the sending and receiving area

Ideally, the decision on the extent and location of the sending and receiving parcels will be derived from digital cadastral data and based on planning considerations. Unfortunately, digital cadastral data at parcel level does not exist for the whole of Switzerland. Furthermore, at this point of time it is not possible to consider all required characteristics of sending and receiving areas (cf. section above) in their designation due to incomplete data. Instead, in our modeling the results of the study of Fahrländer Partner (2008) are used. Fahrländer Partner (2008) calculated the future demand for building zones based on different scenarios and gathered information on the current reserves of undeveloped building zones at municipality level in Switzerland. Based on their data, it is possible to define the quantity of sending and receiving areas for each municipality until 2020. Those areas are then divided into smaller parts, so that the resultant parts represent realistic parcel sizes. This division is done by using a database on building zone parcels (based on 91,000 transactions over the last 20 years) as an empirical example (Wüest und Partner AG, 2011) and digital cadastral data from the Cantons of Zurich and Thurgau.

The above mentioned database is also used to statistically estimate the utilization factor per parcel. In Switzerland, the utilization factor UF determines – together with the parcel area – the legally allowed floor area per building zone parcel and thus the quantity of TDR per parcel. The values for the UF lie between approximately 0.1 for rural areas and 1.3 for urban areas. In order to calculate the allowed gross floor area on a building zone parcel, this factor has to be multiplied with the parcel area (cf. eq. 2-1)

Additionally, we assign to the individual parcels different landowner categories. This is done by using land registry data of various municipalities in the Canton of Grisons, as well as transaction data of undeveloped land parcels (building and agricultural zones) of the Cantons of Zurich and Fribourg.

Designing a TDR, allocation and trading principles

The equation used to define the number of TDR per parcel is:

$$q = A * UF \qquad (2\text{-}1)$$

where q is the quantity of TDR per parcel, A is the parcel area, and UF the utilization factor.

There is a primary free allocation for the landowners in the sending area (called ‘senders’ or ‘sender agents’)[14]. The senders may choose to sell their awarded TDR.

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[14] The free allocation of the TDR to the present landowners is known as ‚grandfathering principle‘.

The landowners in the receiving area (called ‘receivers’ or ‘receiver agents’) need to buy a certain number of TDR to be allowed to develop their parcel. The number of TDR they need will depend on the parcels’ size and the utilization factor (cf. eq. 2-1).

In order to promote high density development in the receiving area and full compensation of the loss of the development possibility in the sending area, both the receivers and senders can only sell/buy the TDR per parcel as a whole (called ‘TDR bundle’)[15]. This restriction has the additional advantage of reducing the number of transactions, which in turn reduces the overall transaction costs[16]. The chosen auction mechanism will be described in the next section and section 2.3.4.

Trading mechanism and trading process

The trading of the TDR will take place on a TDR platform (called ‘TDR bank’) according to the rules of a multi-unit double auction (MDA) with a uniform price[17]. MDAs are frequently employed in stock markets and also for auctioning emission permits (cf. e.g. trading mechanism in the European Energy Exchange EEX[18]).

Here, the choice of MDA shall not be explained by discussing the various forms of auctions[19], however, one important reason for applying a MDA with a uniform price and not e.g. a two-sided Vickrey auction may be mentioned: as the market players (here: senders and receivers) can own more than one parcel of land and therefore participate with more than one order (asks and bids) in the market, a two-sided Vickrey auction would not be efficient[20]. This is because in Vickrey’s (1961) considerations, the market players are only allowed to make one order for the sake of truthfulness. In the case of TDR and for the society as a whole, efficiency is one of the key goals and more important than maximizing the individual revenue. If the latter is a goal, other auction would be applied (Krishna, 2002).

Applied to the TDR market, the trading works as follows (cf. Fig. 2-4): the senders who want to participate in the market, post an ask (request) with their desired price per TDR, and the receivers who

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[15] The receivers have to buy TDR for the maximum allowable gross floor area. This is an incentive for high density development. The rules have been elaborated and defined in a workshop with spatial planning and real estate experts (cf. also footnote 35).

[16] We mean costs associated with the exchange of goods or services, including information, negotiation, communication and control costs.

[17] One-sided auctions (e.g. English auction, Dutch auction etc.) would not be suitable for the trade of TDR, because both sellers (senders) and buyers (receivers) should have the opportunity to submit their price expectations through asks and bids, as in a MDA (multi-unit double auction which is a two-sided auction).

[18] http://www.eex.com, accessed: 2011-10-13.

[19] Further information on auction theory and applications can be found e.g. in Huang et al., 2002; Klemperer, 2004; Krishna, 2002; McAfee and McMillan, 1987; Vickrey, 1961.

[20] According to Krishna (2002), ‘efficiency‘ in an auction means that the object (here: TDR) ends up in the hands of the person who values it the most.

want to participate in the market, post a bid with the price they are willing to pay for the TDR they need. Then, at the end of the trading period (representing one year, explanation follows), the asks are sorted by price in ascending, the bids in descending order, and the market clearing price is calculated: it is the price at the intersection of the ask- respectively bid-curve (cf. Fig. 2-4 and Fig. 2-7). The senders with an ask price below or equal the market clearing price and the receivers with a bid price above or equal the market clearing price are successful traders. All the other market participants are unsuccessful and have the opportunity to participate in the next auction with probably adapted ask- respectively bid-prices (cf. adaptation in sections 2.3.2 and 2.3.3).

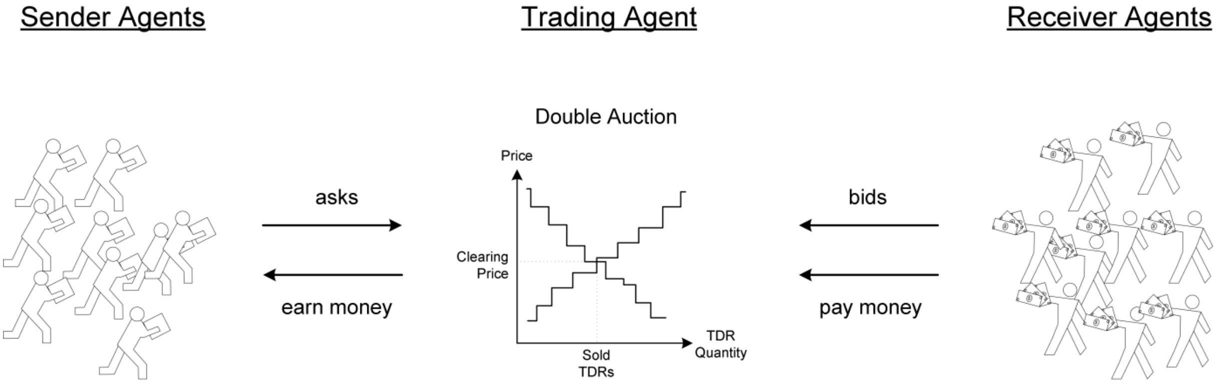

Fig. 2-4: TDR auction.

For an implementation of a TDR program, we propose running two rounds of five auctions each, with one year between each auction. The total time required to action five auctions should be sufficient for the municipalities to adapt their zoning plans for the next round. Furthermore, it is proposed that the municipalities designate sending and receiving areas by parcels and in given intervals. This should prevent a rampant building boom in the receiving area, and hence the supply and demand should be kept in balance.

Fig. 2-5 summarizes and illustrates the main steps and the procedure involved in a TDR program in Switzerland.

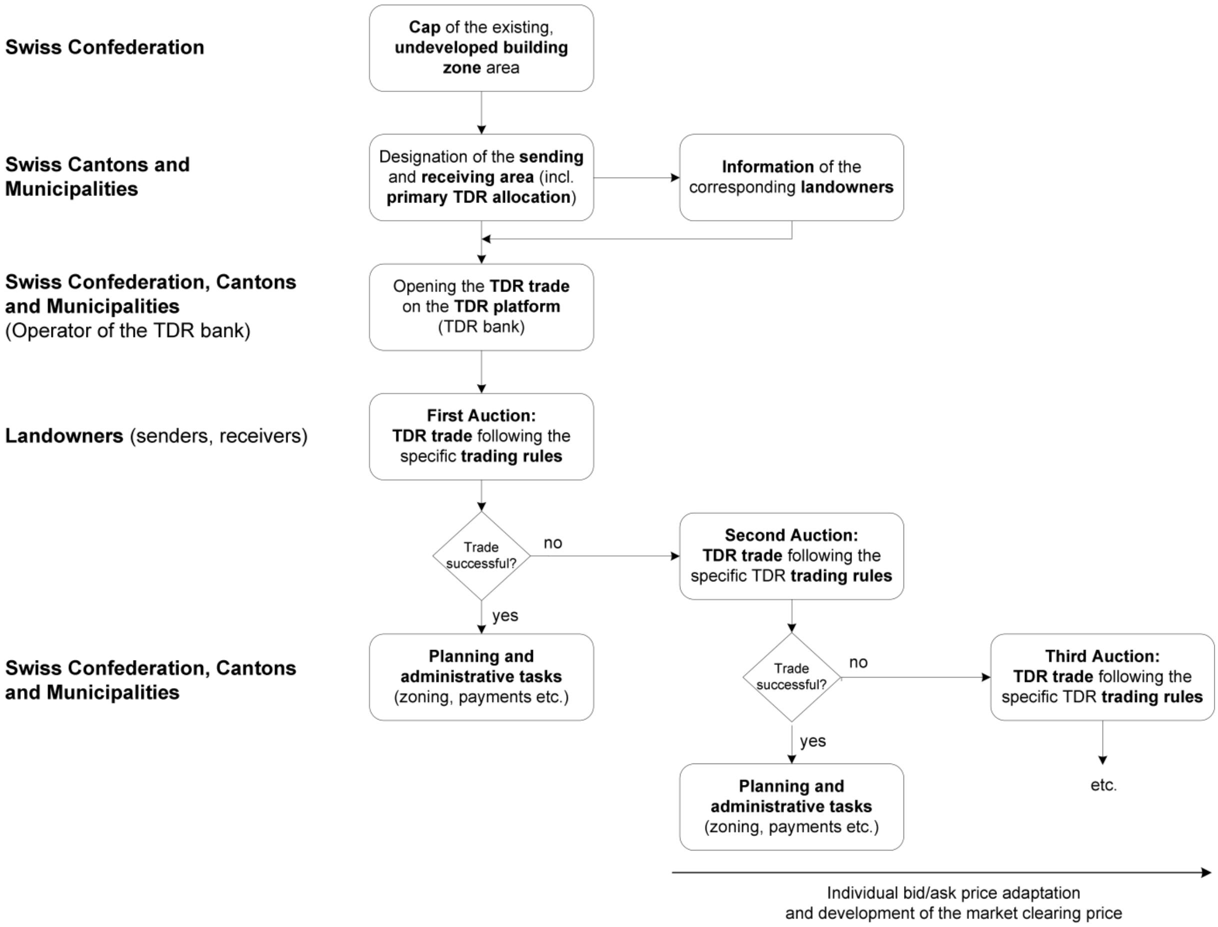

Fig. 2-5: Main steps and procedure of the TDR program in Switzerland.

2.2.4 Agent-based modeling

The following paragraph will briefly introduce agent-based modeling and in particular it will discuss relevant applications of agent-based land-use models.

Agent-based modeling is a simulation instrument which has raised strong interest in the last two decades (cf. e.g. Batty, 2005; Berger et al., 2002; Gilbert, 2007; Hurtubia, 2012; North and Macal, 2007; Parker et al., 2002). ABM, as applied to social processes, uses concepts and tools from both the social and computer sciences. It represents a methodological approach that permits advancement in two important scientific endeavors: 1) the testing, refinement, and extension of existing theories that have proved to be difficult to formulate and evaluate using standard statistics and mathematics; and 2) a deeper understanding of fundamental causal mechanisms in multi-agent systems (MAS), the study of which is currently separated by artificial disciplinary boundaries (North and Macal, 2007; Parker et al., 2002). The multi-agent systems facilitate the consideration of inter-agent linkages as well as linkages between agents and the environment, thus allowing for the modeling of highly dynamic and complex processes. This high complexity is due to the fact that each agent (representing e.g. a landowner) is an individual entity who shares information and negotiates with the other agents in a defined scenario.

Contrary to the traditional top-down modeling approaches, ABM is bottom-up, and the researcher defines behavioral rules at the agent level (cf. e.g. Deadman et al., 2004). Such rules often refer to the utility-function of agents (cf. North and Macal, 2007). When the simulation runs, the researchers observe the agents' behavior over time and its effect for instance on the agents environment. This approach provides an improved understanding of the interplay between individual decision-making and aggregated outcomes.

The simulation of a TDR market can be classified as ABM related to land use. According to Matthews et al. (2007) the ABLUMs (Agent-based land-use models) can be categorized in five broad areas of application: 1) policy analysis and planning (cf. e.g. Happe et al., 2006), 2) participatory modeling (cf. e.g. D'Aquino et al., 2003), 3) explaining spatial patterns of land use or settlement (cf. e.g. Parker and Meretsky, 2004), 4) testing social and economic science concepts (cf. e.g. Polhill et al., 2001), and 5) modeling land use functions (cf. e.g. An et al., 2005).

Our model, which simulates a land market[21], belongs to the third and fourth categories. A model that captures a similar topic to ours is the ALMA (Agent-based Land MArket) model developed by Filatova et al. (2009). These authors link the advantage of geographic cellular land use models with the strengths of economic models such as bid and ask price formation models. There are several aims, of which four are particularly relevant: modeling the behavioral drivers of land-market transactions and the ensuing formation of bid and ask prices, the analysis of the relative gains from trade resulting from the market transactions, and of outputs with macro-scale economic and landscape patterns.

The model that we develop is different as the spatial component is – instead of a regular grid of cells – implicitly implemented in the model through geographically assigned data (e.g. cf. section 2.2.3). Furthermore, it uses empirical data regarding willingness to pay (WTP) resp. willingness to accept (WTA) instead of theoretical assumptions about prices. Finally, the price negotiation is not bilateral, it is rather based on a multi-unit double auction price mechanism with a uniform price.

Besides the abovementioned examples of application areas of ABLUMs, there exist several further models for examining the influence of agents on urban land-use dynamics and land markets (cf. e.g. Brown and Robinson, 2006; Magliocca et al., 2011; Parker and Filatova, 2008; Polhill et al., 2008 or

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[21] The reasons for modeling markets, particularly land markets, are explained at length by Parker and Filatova (2008). Further and more detailed information about overall market design for ABM can be found in Marks (2006), general information on agent-based models can be found in Gilbert (2007) or North and Macal (2007).

Robinson and Brown, 2009). However, such models have not been used to simulate a TDR market and to analyze the economic and land use impact. Our proposed model is designed so that it can fill this gap by producing an ABM simulating those markets in Switzerland.

2.3 Agent-based model for a Swiss TDR market

In this section we will describe the details involved with properties, initialization, behavior and adaptation of the agent-based model for simulating a TDR market in Switzerland (abbreviated 'TDR-ABM'). No particular agent based model description template has been used.

2.3.1 Types of agents, their properties and their interplay

In the simulation model[22] there are three basic types of agents, which are specified separately in subsequent sections: senders, representing landowners in the sending area, receivers, representing landowners in the receiving area, and one trading agent, representing the market platform.

The properties of each agent are stored in state variables during the simulation in discrete time steps $t = 1, 2, \ldots, n$. In the first step $t = 1$ the state variables are initialized. Then, in each iteration t (including the first) the agents behave according to the currently stored values in their state variables, that is, they take an appropriate action. After acting, each agent adapts its state variables and thus its behavior for the subsequent iteration.

The agent interplay and main actions have been outlined conceptually in section 2.2.3 and are illustrated as a concrete ABM in Fig. 2-6 along with:

- all agent states[23] (agent-internal memory to remember what to do subsequently, i.e. in $t+1$);
- transitions between the states;
- schedule (indicated by 'wait until t + 1').

Note that 'offerers' are sender agents having decided to send, and 'bidders' are receiver agents having decided to receive. Furthermore, 'market clearing' means determining the price and quantity at the intersection of the cumulated ask- and bid-curve. Since sender and receiver agents do not depend directly on each other within one iteration t, each of their 'initialization', 'decision', 'action' and 'adaptation' can be scheduled arbitrarily, for instance in random order.

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[22] The simulation has been programmed in Java with use of the free, and open source agent-based modeling and simulation platform Repast Simphony (http://repast.sourceforge.net, accessed: 2012-09-15). The code can be obtained by contacting Gianluca Menghini. For a screenshot of the programmed simulation see: Fig. A-1.

[23] Not to be confused with state variables as a general term. The 'agent state' is one of the agent's state variables.

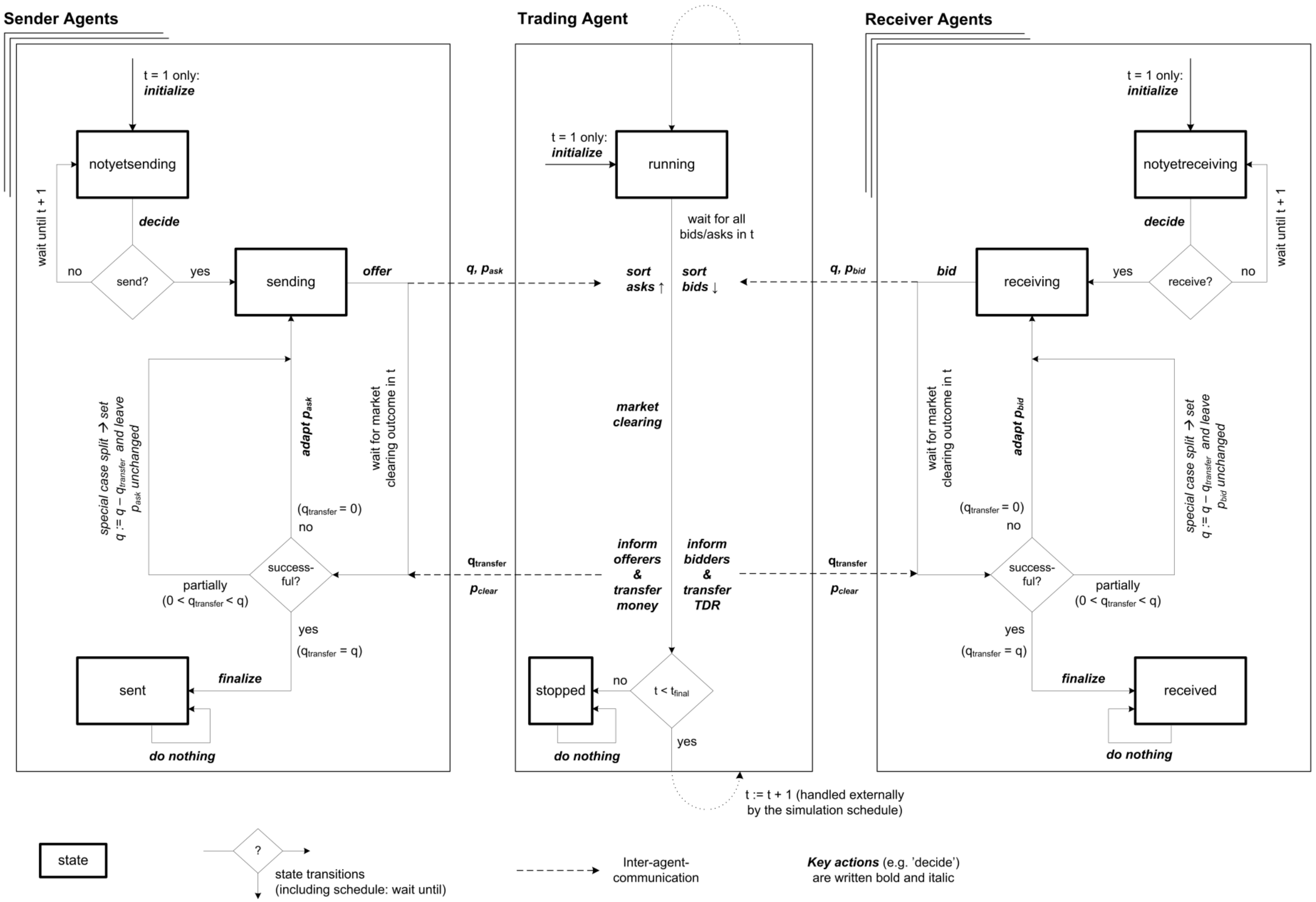

Fig. 2-6: Agent’s states and transitions, actions and communication for some iteration *t*.

2.3.2 Sender agents

In sections 2.3.2 to 2.3.4 information relevant for the simulation is presented in detail. This presentation follows the three agent types and includes the four categories ‘state variables’, ‘initialization’, ‘behavior’ and ‘adaptation’.

State variables

Sender and receiver agents are characterized by the following state variables (properties displayed in Table 2-1):

Table 2-1: State variables of sender and receiver agents (differing variables of sender and receiver agents are highlighted in grey).

Sender agents	**Receiver agents**
Parcel-ID: $\boldsymbol{ID} \in \mathbb{N}$	Parcel-ID: $\boldsymbol{ID} \in \mathbb{N}$
Landowner category: $\boldsymbol{C} \in$ {„Corporation/Limited Liability Partnership”, “Bank/Insurance Company”, “Confederation/Canton/Municipality”, “Individual/Married Couple/Simple Partnership”, “Cooperative/Association/Foundation/Pension Fund”, “Others/rest”}	Landowner category: $\boldsymbol{C} \in$ {„Corporation/Limited Liability Partnership”, “Bank/Insurance Company”, “Confederation/Canton/Municipality”, “Individual/Married Couple/Simple Partnership”, “Cooperative/Association/Foundation/Pension Fund”, “Others/rest”}
Parcel area: $\boldsymbol{A} \in \mathbb{R}^{+}$	Parcel area: $\boldsymbol{A} \in \mathbb{R}^{+}$
Utilization factor: $\boldsymbol{UF} \in \mathbb{R}^{+}$	Utilization factor: $\boldsymbol{UF} \in \mathbb{R}^{+}$
Building land price per square meter (in municipality): $\boldsymbol{BLP} \in \mathbb{R}^{+}$	Building land price per square meter (in municipality): $\boldsymbol{BLP} \in \mathbb{R}^{+}$
Agricultural land price per square meter (in municipality): $\boldsymbol{ALP} \in \mathbb{R}^{+}$	Agricultural land price per square meter (in municipality): $\boldsymbol{ALP} \in \mathbb{R}^{+}$
Willingness to accept (minimum price per TDR): $\boldsymbol{WTA} \in \mathbb{R}^{+}$	Willingness to pay (maximum price per TDR): $\boldsymbol{WTP} \in \mathbb{R}^{+}$
Current Agent state: $\boldsymbol{s} \in$ {„notyetsending“, „sending“, „sent“}	Current Agent state: $\boldsymbol{s} \in$ {„notyetreceiving“, „receiving“, „received“}
Quantity of TDR to sell: $\boldsymbol{q} \in \mathbb{N}_0$	Quantity of TDR to buy: $\boldsymbol{q} \in \mathbb{N}_0$
Probability to enter into the sending and trading process: $\boldsymbol{p_{send}} \in [0,1] \subset \mathbb{R}_0^{+}$	Probability to enter into the receiving and trading process: $\boldsymbol{p_{receive}} \in [0,1] \subset \mathbb{R}_0^{+}$
Current ask price per TDR: $\boldsymbol{p_{ask}} \in \mathbb{R}^{+}$, where $\boldsymbol{p_{ask}} \geq \boldsymbol{WTA}$	Current bid price per TDR: $\boldsymbol{p_{bid}} \in \mathbb{R}^{+}$, where $\boldsymbol{p_{bid}} \leq \boldsymbol{WTP}$

Ask price initialization factor: $\boldsymbol{i} \in \mathbb{R}^+$	Bid price initialization factor: $\boldsymbol{i} \in \mathbb{R}^+$
Ask price adaptation factor: $\boldsymbol{a} \in \mathbb{R}^+$	Bid price adaptation factor: $\boldsymbol{a} \in \mathbb{R}^+$

Note the distinction between variable names in upper and lower case: the former (upper case) point to a constant property (initialized once and unchanged during the simulation) and the latter denote either working variables (changed throughout the simulation) or model parameters (fixed or subject to sensitivity analysis within this paper).

Initialization

Note that paragraph titles within the following sub-sections (up to section 2.4) refer to the 'key actions' highlighted in Fig. 2-6.

initialize (cf. Fig. 2-6)

In the very first iteration sender agents' state variables need to be initialized. Data for variables *ID, C, A, UF, BLP* and *ALP* are imported directly from a text file[24] which essentially contains the data described in section 2.2.3 in the format as illustrated in Table A-1 (cf. appendix A; each row represents one agent with its properties). The remaining state variables are calculated endogenously in the simulation or proposed for sensitivity analysis.

$$s := \text{„notyetsending“} \tag{2-2}$$

All the sender agents start in the state „notyetsending“: the quantity of TDR initially allocated to a parcel and thus to a sender (cf. section 2.2.3) is determined by:

$$q := A * UF \tag{2-3}$$

with given parcel area *A* and utilization factor *UF*.

WTA represents the minimum compensation, that a sender wants to receive for the loss of the development opportunity on its parcel and is calculated (as a price per TDR) by:

$$WTA := (BLP - ALP) * A / q \tag{2-4}$$

using the difference in the value of a building zone (before TDR sale; *BLP*) and an agricultural zone parcel (after TDR sale; *ALP*) in the corresponding municipality (cf. also eq. 3-1). Note that in a further version this calculation will be adapted with the results obtained by an empirical study[25].

For the sake of simplicity and assuming all landowners seek to make some profit, the initial ask price is set to 110 percent of *WTA*:

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[24] We choose to store all agent data row-wise in text files for the sake of software independence and in order to spatially connect them in a straight-forward way using a Geographic Information System – e.g. by joining through the parcel-ID.

$p_{ask} := WTA * (1+i)$ (2-5)

$i := 0.1$ (2-6)

where i is assumed equal for all senders in this article, but could be specified for each landowner category separately[25]. If a sender agent is not successful with its initial ask price, it is decreased using a random ask price adaptation factor (further specified in sub-section *adaptation*):

$a \in [0.02, 0.04]$ (2-7)

So far there is no empirical experience or data about the probability p_{send} to enter the sending and trading process (for each landowner category). Its variation is part of the parameter sensitivity analysis in section 2.4.2 (cf. also Fig. A-3 in the appendix A) and is initialized as follows:

$p_{send} \in [0, 1]$ (2-8)

Behavior

decide (cf. Fig. 2-6)

Before each auction, all sender agents in the state of ‘notyetsending’ decide whether to enter in the sending process or not. In the present implementation this decision is based on a simple random model: with probability p_{send} an agent starts sending in the current iteration t (state transition to ‘sending’), otherwise it repeats deciding in $t+1$.

offer (cf. Fig. 2-6)

Once a sender agent has decided to enter into the sending process and thus is in state ‘sending’, it submits an offer for a bundle of q TDR with a price p_{ask} per TDR in every iteration until successful.

finalize (cf. Fig. 2-6)

After having made an offer, sender agents wait for the answer of the trading agent in the same iteration. If the TDR bundle has not been traded (or just partly in the special case of a split, cf. section 2.3.4), the agent continues offering in the next iteration with an adapted ask price. However, in case of success it finalizes, that is, changes its state to ‘sent’ and calculates its surplus according to (cf. also Fig. 2-7):

$sur := (p_{clear} – WTA) * q$ (2-9)

where p_{clear} is the market clearing price (cf. section 2.3.4) and *WTA* the minimum price per TDR required by the landowner.

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[25] At this point of the work, the initialization of these values is set; empirical values will be collected through a survey (cf. chapter 3).

Note that in the present model each landowner category behaves (and initializes and adapts) the same way. However, in later versions of the TDR-ABM it is intended to define individual sender behavior rules for each landowner category *C*, which we model using inheritance in object-oriented fashion: every sender agent gets a subtype according to *C* – with its own category-specific definition of the initialization, decision and adaptation model (other behavior is identical among all landowners).

Adaptation

adapt (cf. Fig. 2-6)

If a sender agent's offer has not been traded successfully (ask price is too high or TDR are just partly sold in the special case of a split, cf. section 2.3.4), it recalculates the current ask price p_{ask} according to the following adaptation model:

$$p_{ask} := \max(p_{ask} * (1 - a) , WTA) \quad (2\text{-}10)$$

where *a* corresponds to the ask price adaptation factor introduced in equation 2-7 and is allocated a random number based on the real interval between 2 and 4 percent (sampled anew in every iteration). When an agent decided to send and thus is in state 'sending', it participates in the whole auction process and adapts its ask price until the agent's specific *WTA* is reached. For the sake of simplicity, the values for *a* are chosen so that the adapted ask prices lie close to *WTA* after 5 auctions.

2.3.3 Receiver agents

State variables

The state variables of the receiver agents are listed in Table 2-1.

Initialization

initialize (cf. Fig. 2-6)

Similar to the sender case, data for the receiver agents' variables *ID*, *C*, *A*, *UF*, *BLP* and *ALP* are imported directly from the same text file (cf. Table A-1 in the appendix A) into the TDR-ABM, and the remaining state variables are calculated endogenously in the simulation or proposed for the sensitivity analysis:

$$s := \text{„notyetreceiving“} \quad (2\text{-}11)$$

$$q := A * UF \quad (2\text{-}12)$$

$$WTP := (BLP - ALP) * A / q \quad (2\text{-}13)$$

$$p_{bid} := WTP * (1 - i) \quad (2\text{-}14)$$

$$i := 0.1 \quad (2\text{-}15)$$

$$a \in [0.02, 0.04] \tag{2-16}$$

$$p_{receive} \in [0, 1] \tag{2-17}$$

The willingness to pay *WTP* is calculated in the same way and with the same considerations as for the sender agents. In equations 14 and 15 it is assumed that the receiver agents start with a price equal to 90 percent of their *WTP*. If a receiver agent is not successful with its initial bid price, it is randomly increased via a random bid price adaptation factor, which is further specified in section 2.3.3 (subsection *adaptation*).

The initial value of all other state variables like $p_{receive}$ are chosen in the same way as for the sender agents.

Behavior

decide (cf. Fig. 2-6)

Before each auction, all receiver agents in state 'notyetreceiving' decide whether to enter in the receiving process or not. In the present implementation this decision is based on a simple random model: with probability $p_{receive}$ an agent starts sending in current iteration t (state transition to 'sending'), otherwise it repeats deciding in $t+1$.

bid (cf. Fig. 2-6)

Once a receiver agent has decided to enter into the receiving process and thus is in state 'receiving', it submits a bid for a bundle of q TDR with a price p_{bid} per TDR in every iteration until successful.

finalize (cf. Fig. 2-6)

After having made a bid, receiver agents wait for the answer of the trading agent in the same iteration. If the TDR bundle has not been traded (or just partly in the special case of a split, cf. section 2.3.4), the agent repeats bidding in the next iteration with an adapted bid price. However, in the case of success it finalizes, that is, changes its state to 'received' and calculates its surplus according to (cf. also Fig. 2-7):

$$sur := (WTP - p_{clear}) * q \tag{2-18}$$

where p_{clear} is the market clearing price (cf. section 2.3.4) and *WTP* the maximum price per TDR the landowner is willing to pay.

Note that also the receiver agents so far behave all the same (but could be specified individually for instance depending on landowner category *C*).

Adaptation

adapt (cf. Fig. 2-6)

If a receiver agent's bid has not been traded successfully (the price is too low or TDR are just partly bought in the special case of a split, cf. section 2.3.4), it recalculates the current bid price p_{bid} according to the following adaptation model:

$$p_{bid} := \min(p_{bid} * (1+ a) , WTP) \qquad (2\text{-}19)$$

where a corresponds to the bid price adaptation factor introduced in equation 16 and is allocated a random number based on the real interval between 2 and 4 percent (sampled anew in every iteration). When an agent has decided to receive and thus is in state 'receiving', it participates in the whole auction process and adapts its bid price until the agent's specific *WTP* is reached. For the sake of simplicity, the values for a are chosen so that the adapted bid prices lie close to *WTP* after 5 auctions.

2.3.4 Trading agent – the auctioneer

State variables

The trading agent is characterized by various state variables which are mostly used for intermediate calculation steps. However, four variables are of particular importance since they represent the macroeconomic outcome of each trading cycle and provide an aggregated view of all offering and bidding agents:

- Market clearing price: $\boldsymbol{p_{clear}} \in \mathbb{R}^+$
- Total quantity of TDR supply: $\boldsymbol{q_{supply}} \in \mathbb{N}_0$
- Total quantity of TDR demand: $\boldsymbol{q_{demand}} \in \mathbb{N}_0$
- Total quantity of TDR sold: $\boldsymbol{q_{trade}} \in \mathbb{N}_0$

Initialization

initialize (cf. Fig. 2-6)

The state variables of the trading agent are all initialized with zero.

Behavior

In accordance with the principle of an MDA, the trading agent calculates the market clearing price (cf. Fig. 2-6 and Fig. 2-7) and ensures the communication between the supply (sender agents) and demand side (receiver agents). The following processes are repeated in each auction:

sort asks and bids (cf. Fig. 2-6)

After submission of all asks and bids (hereinafter also referred to as ‘orders’), the trading agent sorts the orders according to their price. Asks are sorted ascending, bids descending.

market clearing (cf. Fig. 2-6)

Then the trading agent calculates the market clearing price p_{clear}. It is the price at the intersection of the demand and supply curve (cf. Fig. 2-7).

In the majority of cases, the calculation of the market clearing price is not possible without splitting up the last successful order. The reason for this fact is the different sizes of the traded TDR bundles. Fig. 2-7 illustrates the situation of splitting up the last successful order of a sender agent. In such a case, the affected agent participates automatically in the subsequent auction with the part of its TDR bundle being left and with an adapted ask/bid price. If the ‘split’ occurs in the last auction, the split part of the TDR bundle is bought/sold by the operator of the TDR bank (e.g. government).

All possible configurations for calculating the market clearing price are listed in Fig. A-2 (appendix A) along with the implemented solutions which are not further discussed here.

Moreover, Fig. 2-7 illustrates graphically all receiver and sender surpluses. The surplus for the ‘society’ can be seen as the sum of the receiver and sender agents’ surpluses. However, the aim of the TDR-ABM is not to maximize the surpluses, rather to identify the resulting prices and TDR quantities traded with the chosen auction mechanism.

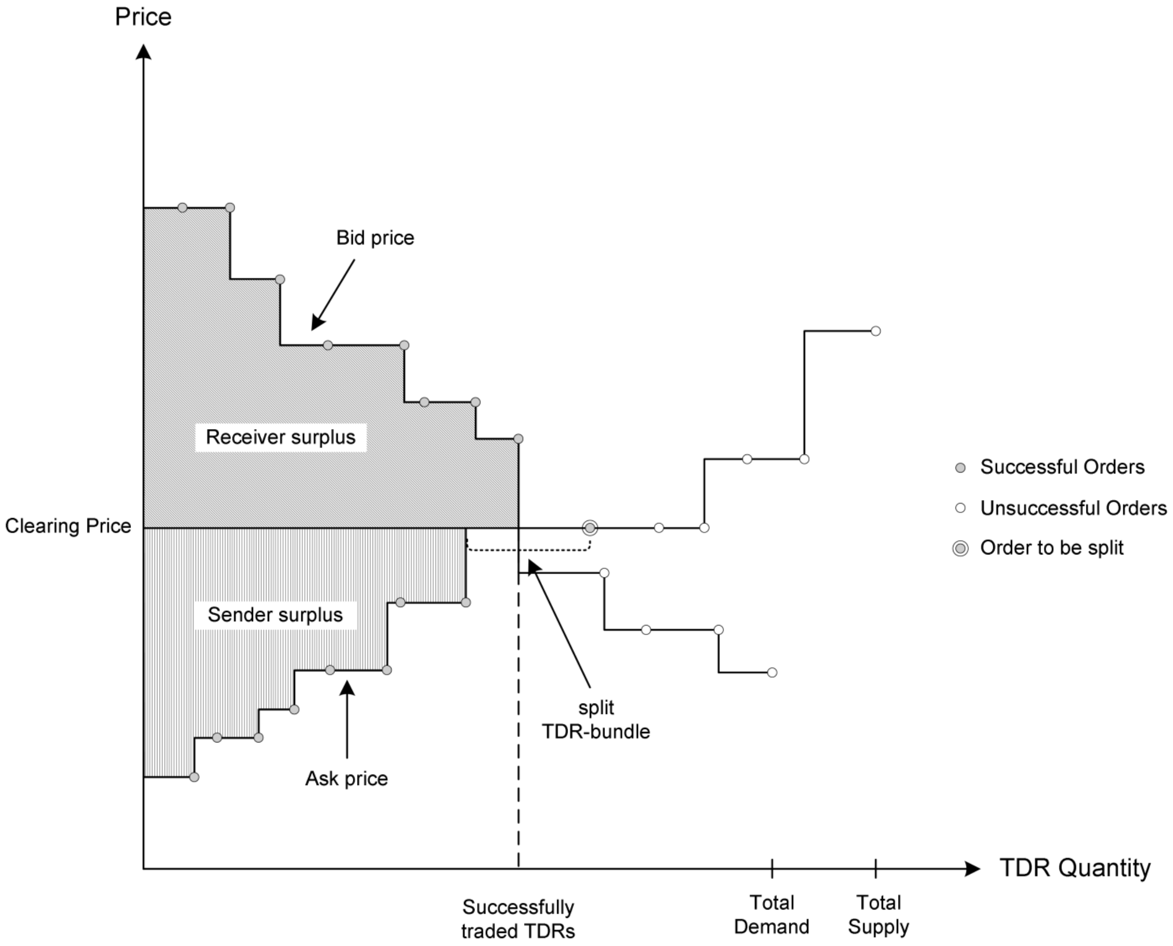

Fig. 2-7: Calculation of the market clearing price.

inform offerers/bidders and transfer money/TDR (cf. Fig. 2-6)

Finally, the trading agent informs each successful sender and receiver about its trading result, that is, the clearing price p_{clear} and traded quantity $q_{transfer}$. Success occurs when sender agents have $p_{ask} \leq p_{clear}$ and receiver agents $p_{bid} \geq p_{clear}$. All the successful sender agents get the same (uniform) price p_{clear} per TDR and all the successful receiver agents have to pay p_{clear} respectively.

Adaptation

There is no adaptation process for the trading agent. Nevertheless, adaption would be conceivable, if one wants to change the ‘trading rules’ – e.g. in order to receive better model outcomes – during the trading process.

2.4 Evaluation of the model

The program code of the TDR-ABM has been verified through testing random simple data. These results have been compared with manually calculated values by face validation (cf. e.g. Klügl, 2008; North and Macal, 2007). Beside the face validation, a computational performance analysis and a sensitivity analysis of selected parameters have been done.

2.4.1 Computational performance of the TDR-ABM

In order to test the computational performance of the TDR-ABM, datasets with an increasing number of agents (1,000 – 1,000,000) were created and stepwise tested in the simulation. The TDR-ABM was run for each dataset on an ordinary computer (Core Duo Processor with 2.66 GHz and 2.96 GB RAM) and the total computing time was recorded.

Fig. 2-8 illustrates the results of the analysis with the following specifications for all sender as well as receiver agents:

- participation probability $p_{send} = p_{rerceive}$ = 100 percent;
- price adaptation factor a = uniform random number between 2 and 4 percent;
- price initialization factor i = 10 percent;
- n = 10 consecutive auctions;
- TDR-ABM has been run 1,000 times and the computational time has been averaged for each dataset tested.

As Fig. 2-8 shows, the computational time increases in a strong linear form and the model works well, even for 1 million agents (computational time of approximately 150 seconds).

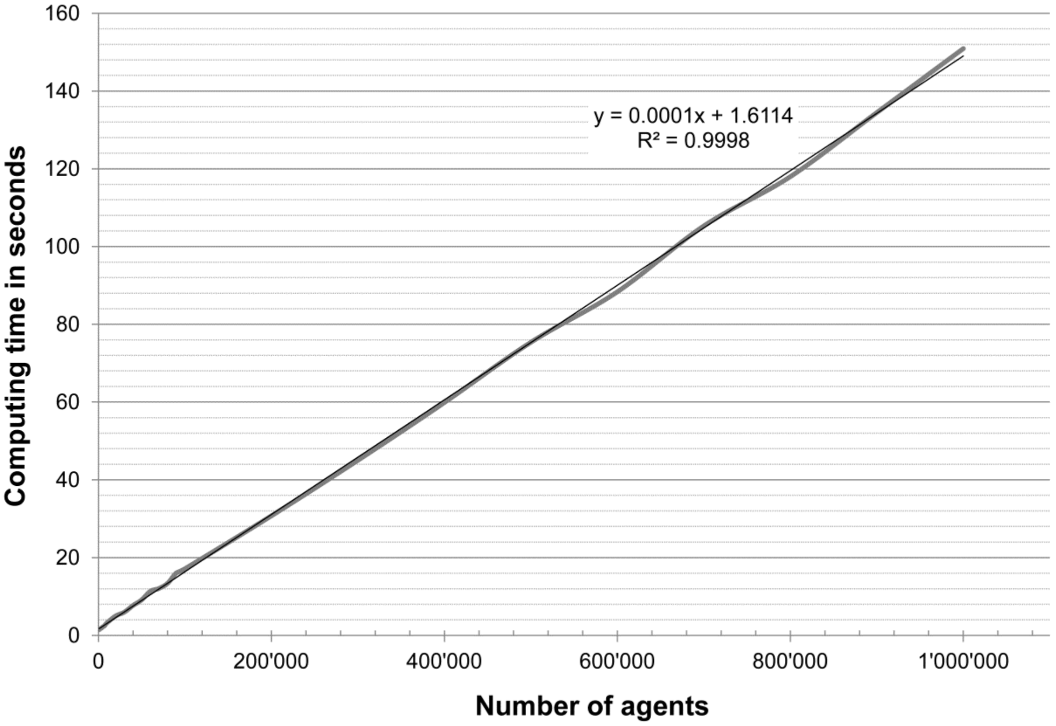

Fig. 2-8: TDR-ABM performance analysis.

2.4.2 Sensitivity analysis of p_{send} and $p_{receive}$

There exist a number of reasons for conducting sensitivity analyses and there are many different ways to do it. According to Hamby (1994), one possible reason is to analyze which parameters contribute most to the output variability and therefore require additional research. Another reason is to examine the consequences of the change of one parameter on the model results. The latter is a goal of this section and it is tested for the two parameters p_{send} and $p_{rerceive}$ which seem to be the most interesting and uncertain, because of highly varying participation rates in existing TDR programs (Pruetz (2003) identified failing and quite successful TDR programs).

A straight-forward method to do the intended analysis is called 'one-at-a-time sensitivity measure' and it is conducted by repeatedly varying one parameter at a time while holding the others fixed (Hamby, 1994)[26].

One-at-a-time sensitivity analysis

To test the influence of p_{send} and $p_{receive}$, the measure for success of the TDR program must be defined. This could be done through the total quantity of traded TDR or the market clearing price either aggregated over time (sum, average) or per single instance (q_{trade}, p_{clear}). A TDR program is successful if as

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[26] It should be noted that this method is likely to miss non-linear interactions.

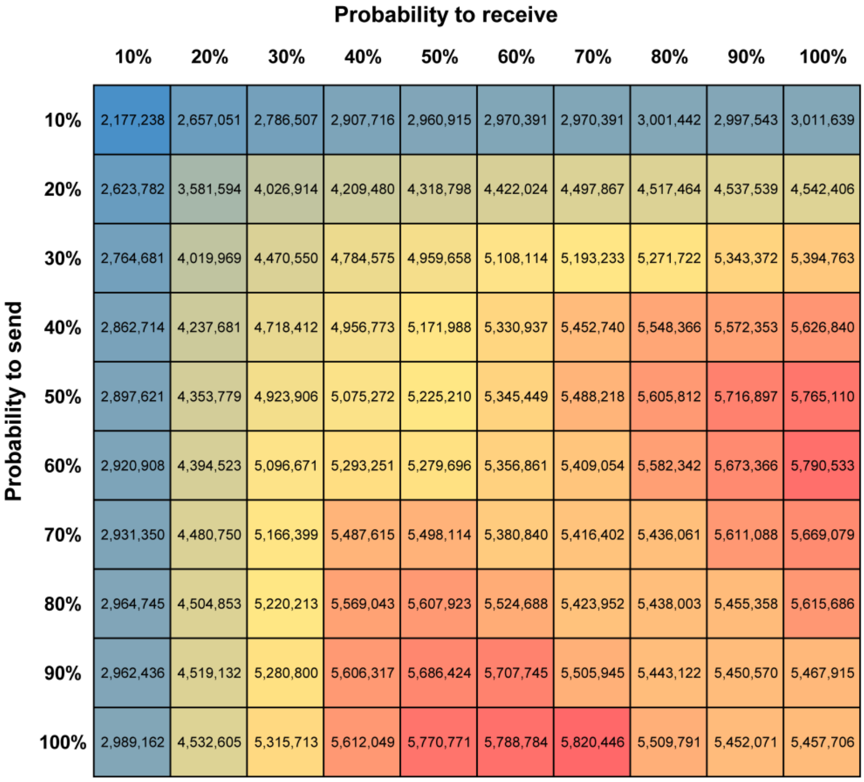
many TDR as possible are sold at a reasonable price. In this context, reasonable means that the total cost for obtaining the right to develop a building zone parcel should remain about the same as before introducing the TDR program.

The sensitivity analysis was performed with the following settings:

- 100 different combinations of the two variables p_{send} and $p_{receive}$, while holding all the others constant;
- Parameter i = 10 percent;
- Parameter a = uniform random number between 2 and 4 percent;
- Approximately 45,000 agents;
- n = 5 consecutive auctions;
- Each combination was run 1,000 times and the results were then averaged over all runs.

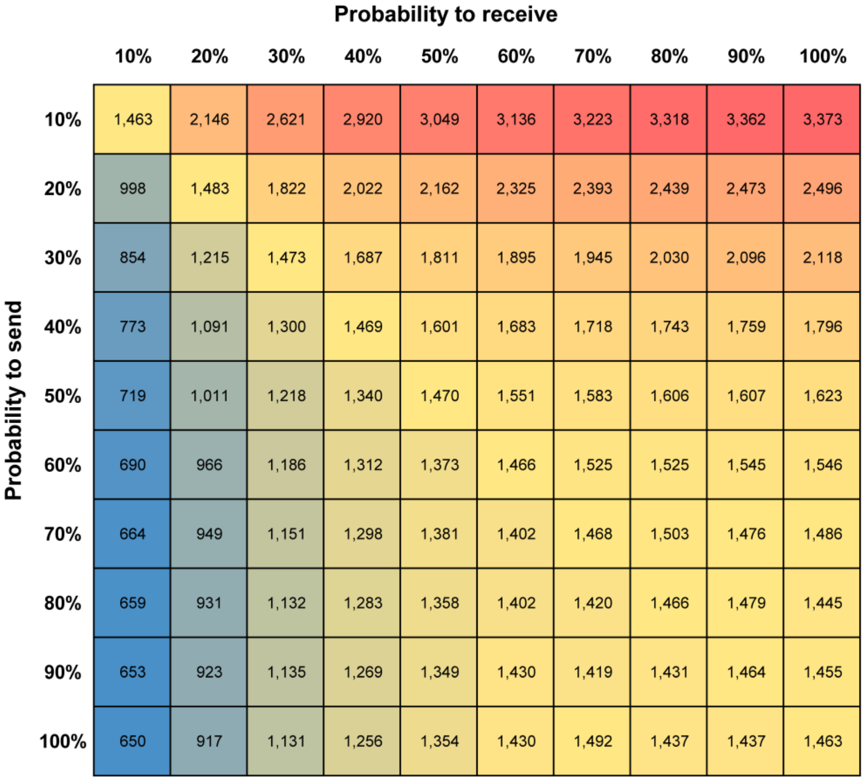
Fig. 2-9 shows the effect of different p_{send} and $p_{receive}$ values on the total quantity of TDR traded over 5 auctions. Fig. 2-10 shows the average clearing price, and Fig. 2-11 shows the variance of the clearing price.

Note that the illustrated effects are the cumulated results of 5 consecutive auctions, which means that the ‘time-dimension’ is not considered. This was done in a further analysis, in which the development of the clearing price during the 5 auctions was analyzed. A selection of the obtained results is shown in Fig. 2-12. For the latter analysis as well, the simulation was run 1,000 times and the values were averaged over all the runs.



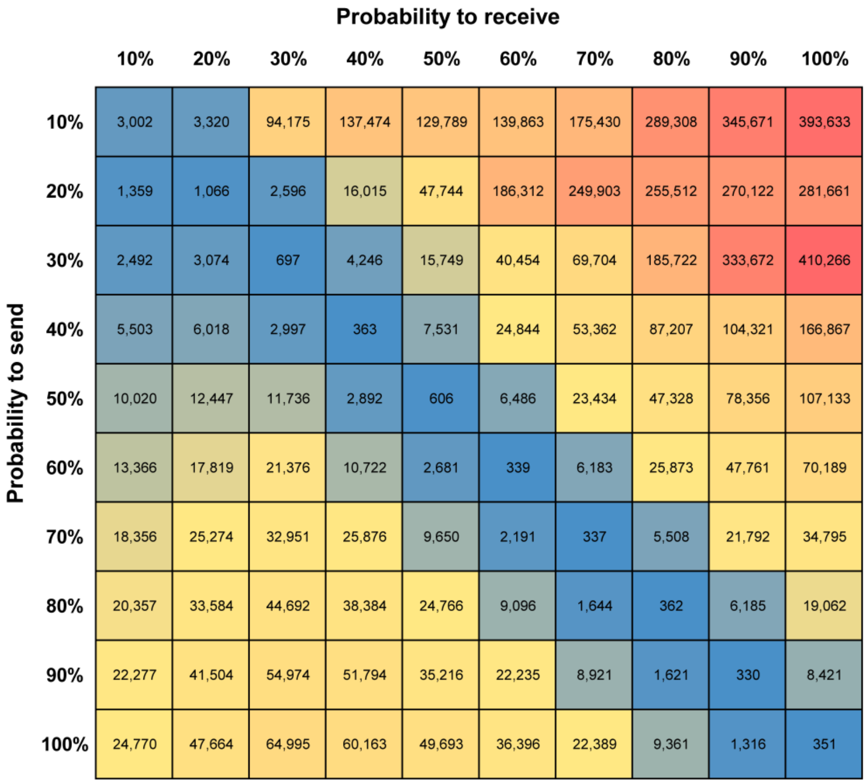
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
10%	2,177,238	2,657,051	2,786,507	2,907,716	2,960,915	2,970,391	2,970,391	3,001,442	2,997,543	3,011,639
20%	2,623,782	3,581,594	4,026,914	4,209,480	4,318,798	4,422,024	4,497,867	4,517,464	4,537,539	4,542,406
30%	2,764,681	4,019,969	4,470,550	4,784,575	4,959,658	5,108,114	5,193,233	5,271,722	5,343,372	5,394,763
40%	2,862,714	4,237,681	4,718,412	4,956,773	5,171,988	5,330,937	5,452,740	5,548,366	5,572,353	5,626,840
50%	2,897,621	4,353,779	4,923,906	5,075,272	5,225,210	5,345,449	5,488,218	5,605,812	5,716,897	5,765,110
60%	2,920,908	4,394,523	5,096,671	5,293,251	5,279,696	5,356,861	5,409,054	5,582,342	5,673,366	5,790,533
70%	2,931,350	4,480,750	5,166,399	5,487,615	5,498,114	5,380,840	5,416,402	5,436,061	5,611,088	5,669,079
80%	2,964,745	4,504,853	5,220,213	5,569,043	5,607,923	5,524,688	5,423,952	5,438,003	5,455,358	5,615,686
90%	2,962,436	4,519,132	5,280,800	5,606,317	5,686,424	5,707,745	5,505,945	5,443,122	5,450,570	5,467,915
100%	2,989,162	4,532,605	5,315,713	5,612,049	5,770,771	5,788,784	5,820,446	5,509,791	5,452,071	5,457,706

Fig. 2-9: Effect of parameters p_{send} and $p_{receive}$ on the total quantity of TDR traded over 5 auctions.



	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
10%	1,463	2,146	2,621	2,920	3,049	3,136	3,223	3,318	3,362	3,373
20%	998	1,483	1,822	2,022	2,162	2,325	2,393	2,439	2,473	2,496
30%	854	1,215	1,473	1,687	1,811	1,895	1,945	2,030	2,096	2,118
40%	773	1,091	1,300	1,469	1,601	1,683	1,718	1,743	1,759	1,796
50%	719	1,011	1,218	1,340	1,470	1,551	1,583	1,606	1,607	1,623
60%	690	966	1,186	1,312	1,373	1,466	1,525	1,525	1,545	1,546
70%	664	949	1,151	1,298	1,381	1,402	1,468	1,503	1,476	1,486
80%	659	931	1,132	1,283	1,358	1,402	1,420	1,466	1,479	1,445
90%	653	923	1,135	1,269	1,349	1,430	1,419	1,431	1,464	1,455
100%	650	917	1,131	1,256	1,354	1,430	1,492	1,437	1,437	1,463

Fig. 2-10: Effect of parameters p_{send} and $p_{receive}$ on the average clearing price over 5 auctions in CHF.



	Probability to receive									
Probability to send	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
10%	3,002	3,320	94,175	137,474	129,789	139,863	175,430	289,308	345,671	393,633
20%	1,359	1,066	2,596	16,015	47,744	186,312	249,903	255,512	270,122	281,661
30%	2,492	3,074	697	4,246	15,749	40,454	69,704	185,722	333,672	410,266
40%	5,503	6,018	2,997	363	7,531	24,844	53,362	87,207	104,321	166,867
50%	10,020	12,447	11,736	2,892	606	6,486	23,434	47,328	78,356	107,133
60%	13,366	17,819	21,376	10,722	2,681	339	6,183	25,873	47,761	70,189
70%	18,356	25,274	32,951	25,876	9,650	2,191	337	5,508	21,792	34,795
80%	20,357	33,584	44,692	38,384	24,766	9,096	1,644	362	6,185	19,062
90%	22,277	41,504	54,974	51,794	35,216	22,235	8,921	1,621	330	8,421
100%	24,770	47,664	64,995	60,163	49,693	36,396	22,389	9,361	1,316	351

Fig. 2-11: Effect of parameters p_{send} and $p_{receive}$ on the variance of the clearing price over 5 auctions.

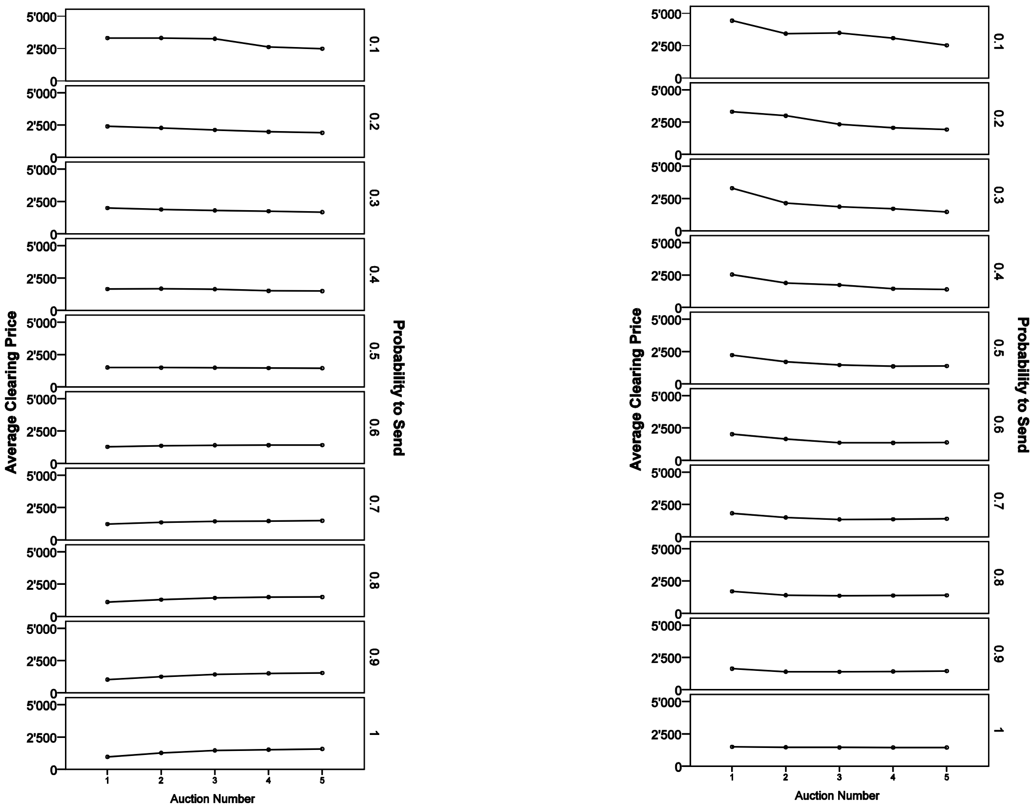


Fig. 2-12: Variation per auction of the clearing price at changing p_{send} and constant $p_{receive}$ values – left: $p_{receive}$ = 50%; right: $p_{receive}$ = 100%.

Fig. 2-9 illustrates a potentially crucial fact: The total quantity of traded TDR (cumulated over 5 auctions) increases with an increasing supply and demand only up to p_{send} = 60% and $p_{receive}$ = 70% (cf. dark red colored regions in Fig. 2-9). This is particularly interesting because it could have been expected that the TDR quantity traded would increase up to full participation with $p_{send} = p_{receive}$ = 100%. This phenomenon might be caused by our decision model in its temporally repetitive application (cf. sub-section *Behavior* in 2.3.2 and 2.3.3) in which probabilities p_{send} and $p_{receive}$ increase like a geometrical series. Lower values of p_{send} resp. $p_{receive}$ increase faster than high values of p_{send} resp. $p_{receive}$, and the ask and bid prices are stepwise adapted for unsuccessful agents.

The results presented in Fig. 2-10 show clearly that the clearing price increases with an increasing demand (high values of $p_{receive}$) and that it decreases with an increasing supply (high values of p_{send}). This is how a ‘normal’ market usually reacts and it underlines that the TDR-ABM reflects empirically observable situations.

Furthermore, in Fig. 2-10 it can be seen that the clearing price is stable at balanced supply and demand (values on the diagonal of the matrix). Possible reasons for this fact are the symmetric assumptions of our model (*WTA* resp. *WTP* and adaption assumptions) and similar initialization (cf. sub-section *Initialization* in 2.3.2 and 2.3.3).

Fig. 2-11 shows considerably higher variance values at high $p_{receive}$ and low p_{send} values. This means that the clearing price varies most with high demand and low supply. In contrast, high supply and low demand seem not to result in such a high variance of the clearing price. The least variance can be observed with balanced p_{send} and $p_{receive}$ values.

The development of the clearing price over 5 auctions can be observed in Fig. 2-12[27]. The two examples demonstrate that the clearing price varies quite strongly in case of low p_{send} and high $p_{receive}$, and vice versa. Additionally, it appears that if p_{send} is larger than $p_{receive}$, the clearing price increases during the 5 auctions, otherwise it decreases. It can also be seen that the clearing price remains quite stable with balanced values of p_{send} and $p_{receive}$. This trend supports the findings in Fig. 2-10 and Fig. 2-11 in which the averaged clearing price over 5 auctions varies only in a narrow band whenever p_{send} and $p_{receive}$ have similar values.

Concerning the results of the sensitivity analysis, it can be concluded that the two parameters p_{send} and $p_{receive}$ are sensitive indeed and thus care needs to be taken with them. In addition, the TDR-ABM seems to produce reasonable and useful results.

As already mentioned, in a later version of the TDR-ABM, various assumptions (e.g. a decision model) will be adapted to the results of an expert survey, and therefore differing effects or trends may emerge. For this reason, we have not discussed these initial findings in more detail.

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[27] All p_{send} and $p_{receive}$ combinations are illustrated in the appendix (Fig. A-3).

2.5 Discussion, conclusion and outlook

2.5.1 TDR specific discussion

In this paper we suggest a TDR program in Switzerland which is the basis for the TDR-ABM. The suggested program was elaborated in detail with Swiss planning experts by taking into consideration both the unique Swiss situation and experience in other countries. However, the conceptual design alone cannot assess the consequences of a practical implementation. This motivated us to develop a simulation framework in order to explore possible impacts of a TDR program in Switzerland. The simulation output aims to provide useful information to facilitate the political discussion of the advantages and disadvantages of the implementation of a TDR program in Switzerland.

An important step in our TDR program is the designation of appropriate sending and receiving areas. In section 2.2.3 we outline the characteristics of these areas and explain the empirical data base to be employed. Using this data, it was possible to prepare suitable (first) input data sets for the simulation.

In our market design we did not allow speculation or banking and borrowing – following a suggestion by Swiss planning experts (to keep the market fluid, avoid prices being distorted). This exclusion also had the advantage of a simplification of the model. These considerations may increase public confidence in a TDR program and reduce strategic behavior (e.g. market power, rent-seeking) that could have a negative impact on cost-effectiveness (Henger and Bizer, 2010), and market fluidity.

We have not placed any emphasis on the monitoring system, trading rules, the need of a market maker or the transaction costs (cf. footnote 16). However, in practice these considerations are important. In Switzerland, most likely the Federal Office for Spatial Development would monitor the system, define the detailed trading rules and also act as market maker to enable entering the market. The transaction costs could be limited by providing easily accessible public information and through the reduction of the number of transactions. The latter was implemented in the TDR-ABM by restricting the trade to TDR bundles.

There is one more specific economic characteristic of the TDR we did not consider. A part of the TDR can have a so-called complementary character. This can occur when the value of the TDR of a parcel is linked to one’s own possession of TDR of another parcel. Such a situation could arise when a large development project is realized which involves several parcels and a buyer/seller is interested in the TDRs of an additional parcel. In such a case, complementarities can lead to high prices for the additional parcel (Berninghaus et al., 2006). Although complementarities are not specifically taken into account in our model, the first model outcomes have shown that the price determination method is quite robust at high prices (cf. section 2.4.2). Therefore, problems due to complementarity should have little impact.

Furthermore, we do not explain what happens at the end of the TDR program, that is when most of the TDR are sold (e.g. 90% of the total TDR quantity). Even though this is not the topic of this paper, at the end of the TDR program, we suggest replacing it with a TPP program (Tradable Planning Permits) (cf. section 2.2.3). In such a follow-up program, the Federal Office for Spatial Development would define a predetermined total permit quantity of TPP for designating new building zones. This total quantity could be distributed – according to a certain distribution formula – to the municipalities which could then trade the TPP amongst each other.

To conclude, the proposed TDR program can be implemented in a ABM (TDR-ABM) so that the simulation can provide information (TDR prices and quantities) for the political discussion in Switzerland. However, it should not be forgotten, that a TDR program is only ‘supplementary to planning’ and it should always be accompanied by other planning instruments.

2.5.2 ABM specific discussion

In this paper we have outlined a plausible agent-based model in order to simulate a TDR market in Switzerland. Our model simulates a ‘true order book’ in which agents submit asks and bids for a specific good (here TDR). According to LeBaron (2006) the implemented method of price determination (cf. sections 2.2.3 (sub-section *Trading mechanism and trading process*) and 2.3.4) is the most realistic from a market microstructure perspective.

The advantage of the ABM is that rational behavior of the agents need not to be assumed as is usually the case in economic models[28]. It is possible to define bounded rationalities which means that different agents can have different rationalities. In our model we implemented three different agent types with specific state variables, behavior and adaptation rules (cf. section 2.3). Because of missing empirical data (e.g. behavior differences of the landowner categories), we introduced randomness (e.g. the decision to enter in the sending/receiving process) and applied several simplifications (e.g. landowner categories behave identically). Despite these simplifications, the evaluation of the model (cf. section 2.4) demonstrates that the model produces reasonable outcomes and that it can be used for further analyses.

The implemented concept of trading multiple units of a good at fixed package sizes (TDR bundles) is quite unique as the price determination is solved through splitting the last successful order at the intersection of the supply and demand curve. In each auction, a maximum of one TDR bundle has to be split. This is most acceptable in the opinion of the authors and given the fact that thousands of agents may participate in the market. The caused efficiency loss is much lower than it would be by implementing another option e.g. a two-sided Vickrey auction. As far as we know, the proposed ABM is the first to include such a special auction form.

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[28] Further reasons and advantages for modeling markets with ABM can be found e.g. in Bousquet and Le Page (2004) or Parker and Filatova (2008).

The implemented provisional solution of subtracting/adding a random value to the *WTA* resp. *WTP* is similar to the one suggested by Gode and Sunder (1993). However, the criticism of Parker and Filatova (2008) that with such an assumption location-specific amenities are not considered, does not hold here. In our model, the *WTP* resp. *WTA* values are initialized through empirical data at municipality level and therefore, the location specific properties (e.g. building zone prices vary according to the location) of TDR are taken into account.

Further, we did not consider imitation effects, special learning mechanisms or a separate perception of the environment. The latter could be taken into account through a new variable reflecting the market situation as Parker and Filatova (2008) suggest (e.g. inflation or interest rate). This could be a possible extension for a further version of our TDR-ABM.

To sum up, the presented TDR-ABM is intended to be a consulting instrument which produces a range of possible outcomes (e.g. TDR prices and quantities) and not a forecasting instrument with one correct value. The advantage of the simulation – compared with a purely analytical solution – is the possibility to assume specific distributions of uncertain parameters (e.g. p_{send} resp. $p_{receive}$ values) and to reduce these uncertainties through thousands of simulation runs. The large number of simulation runs should pose no difficulty, as the results of the performance analysis show (cf. section 2.4.1).

When it comes to furthering this work, the TDR-ABM was improved by incorporating further empirical data (cf. chapters 3 and 4). A survey was carried out to collect data about the behavior regarding various landowner categories involved in a TDR program in Switzerland. The results of the survey were used to calculate or define:

- landowner specific probabilities for the p_{send} resp. $p_{receive}$ values;
- landowner specific functions for the calculation of *WTA* resp. *WTP* values;
- landowner specific adaptation functions (initialization factor *i* and adaptation factor *a*) for the p_{bid} resp. p_{ask} values.

After the calibration of the simulation it was possible to analyze relevant political and economic questions for Switzerland and so to provide more and better outcomes.

3 A survey of market participants to inform the TDR-ABM[*]

Abstract: Urban sprawl is a common phenomenon in many parts of the world. Switzerland is also affected by this phenomenon and its negative consequences. In addition, in Switzerland sprawl is facilitated by an excessive supply of building zones far beyond demand for the next 20 years. We propose to reduce these land-use problems by introducing a limited number of transferable development rights (TDR). As there is little experience with this instrument worldwide, we suggest using an agent-based model (ABM) to simulate the trade of TDR. For reliable and useful simulation results, the ABM needs to be calibrated with empirical data. For this purpose a participant-specific questionnaire survey among four potential landowner categories was conducted. The contacted persons represented either potential sellers or potential buyers of TDR. Each received a questionnaire confronting her/him with a unique realistic situation.

The aim of this paper is to present this questionnaire and more particularly the detailed results of the descriptive and analytical analysis of the survey data to be used in a direct calibration of an ABM. The approach to collect data with a participant-specific survey to directly calibrate an ABM proved successful. The results show that among the differentiated landowner categories there were differences in the willingness to participate in the TDR market and that the stated TDR prices were strongly determined by the theoretical TDR value. Furthermore, enterprises behaved differently than other landowner categories during the proposed five auctions.

Keywords: Transferable development rights (TDR), TDR market, Participant-specific questionnaires, Agent-based model, ABM-calibration

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[*] This chapter is a slightly amended version of the paper "Transferable development rights (TDR) in Switzerland: A survey of market participants to inform an agent-based model" written by Gianluca Menghini, Irmi Seidl and Philippe Thalmann. The paper has been submitted to the *Journal of Environmental Policy & Planning* and is currently 'under review'. The authors would like to thank the Swiss National Science Foundation for funding the project (K-21K1-1224) and Claudia Keller for the assistance in data preparation. Moreover, we thank two anonymous reviewers for their valuable comments on an earlier version of this paper.

3.1 Simulating a market for TDR with an ABM

3.1.1 Underlying practical problem of land use in general and in Switzerland

Urban sprawl is a common phenomenon in widespread parts of the world. European hot spots of urban sprawl are located in highly populated coastal areas, such as Porto, Palermo, Istanbul, and Udine (EEA, 2006). However, Switzerland is also affected by this phenomenon. Over the last 30 years, the Swiss settlement area has increased by 23.5%[29] (and the population by 24%). A large part of this expansion has come at the expense of farmland (IRL, 2003) in common with other hot spots of urban sprawl. Compared with development in high-density areas, urban sprawl is associated with more negative consequences for the environment, higher infrastructure costs, and greater energy consumption (Baumgartner, 2005; Ewing, 2008; Brownstone and Golob, 2009).

Good zoning practice may help preventing sprawl, however, it has failed in many countries. According to Brueckner (2000) there are three major drivers of urban sprawl: population growth, increasing income, and decreasing costs of commuting. An additional reason is that municipalities may not follow planning regulations strictly enough, or the latter have simply been insufficient. All of these points pertain to Switzerland, yet it is the planning practice we highlight here. The municipalities have a strong incentive to increase the area of building zones, in particular as new settlements promise new tax revenues. Depending on what assumptions are made, between 38,000 and 53,000 hectares (17 to 24%) of the existing building zone areas have not been developed. According to ARE (2005, 2008) and Fahrländer Partner (2008) many of the undeveloped building zone areas are unreasonably large[30].

Another problem is the location of these areas. The supply and demand for undeveloped building zones is spatially extraordinarily imbalanced: in the next 30 years, the demand in the agglomerations of the major centers and along major transport routes is expected to significantly exceed the current reserves. However, in the municipalities far away from the centers the situation is completely different. There, the area with undeveloped building zones is significantly larger than the expected demand (Fahrländer Partner, 2008).

The Swiss problem with the building zones is mainly caused by a lax zoning practice of the municipalities and by the tolerance of this unlawful situation at higher political levels, namely the cantons and

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[29] Results of the Areal Statistics 1979/85 – 2004/09 (http://www.bfs.admin.ch/bfs/portal/de/index/themen/02/03.html accessed: 2011-11-02).

[30] According to Fahrländer Partner AG (2008) and ARE (2005), the undeveloped building zone areas could provide space for about two million (additional) people (Switzerland has approximately 8 million inhabitants at present).

the confederation[31]. In Switzerland, local governments have considerable planning autonomy, which tends to make existing spatial planning systems inefficient. Moreover, Switzerland has approximately 2500 municipalities, with each having the right to designate the building zones within its area.

The high land consumption and the imbalanced supply and demand for building zones clearly goes against the principles for economical use of land resources as specified in Art. 1 of the Swiss Federal Act of 22 June 1979 on Spatial Planning. There is general agreement that the current spatial planning instruments are insufficient to overcome this unsustainable growth (ARE 2006; Süess and Gmünder 2005; Zollinger 2006). Moreover, due to vested interests and possible expropriation costs[32] of many landowners, it is too late to redo zoning plans from scratch.

A possible instrument to solve these problems are TDR. TDR are a quantity-controlling, economic instrument based on the concept of tradable usable resources (or emissions). They are applied and discussed for various purposes (e.g. increasing building density, preservation of natural areas, compensation of reduced development possibilities etc.) and in various countries (e.g. USA, Australia, New Zealand etc., cf. Janssen-Jansen et al., 2008). Overall, TDR are considered to be an efficient economic instrument to counteract the widespread problem of inefficient land-use, in particular urban sprawl, as they concentrate development in places with the highest marginal utility. However, there are country-specific differences regarding the problems of land-use, the reasons for it, and the political and judicial framework. Hence, a TDR concept hast to be country-specific as well (Janssen-Jansen et al., 2008).

As TDR have hardly been discussed and so far not been applied in Switzerland, in chapter 2 (first paper) both a concept for a TDR market in Switzerland and an agent-based model (ABM) for simulating the proposed TDR market (called TDR-ABM)[33] is presented. However, the proposed TDR-ABM can only produce reliable and meaningful model results for the political discussion in Switzerland, when it is calibrated with realistic data. In order to gather such calibration data, a questionnaire survey has been conducted. This survey and its results will be presented in this paper.

After a brief description of the TDR concept for Switzerland and the corresponding ABM (cf. section 3.1.2), we will present in detail the survey (cf. section 3.2). Section 3.1.2 (description of the TDR concept and corresponding ABM) is needed to understand the questionnaire. Afterwards (cf. section 3.3),

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[31] For more information about the land use system in Switzerland see:
http://www.vlp-aspan.ch/sites/default/files/ landusech_7.pdf, accessed: 11-13-2012.

[32] According to Swiss law changing the status of building zone land into agricultural land for instance, would mean expropriating the owner, who would then have to be fully compensated.

[33] The purpose of the agent-based simulation is to provide useful information (e.g. TDR supply and demand, TDR prices) for the political discussion about the implementation of TDR in Switzerland. Without information and research proving its worth, both in how it functions and the effects it has, there will be little political willingness to implement such an instrument (Gmünder, 2010).

we present descriptive results of the survey and then different statistical models. We conclude with a discussion, a summary of the main findings and a short outlook to the future (cf. section 3.4 and 3.5).

3.1.2 TDR concept and corresponding agent-based model

TDR concept for Switzerland

In Switzerland, only a few studies on the possible application of TDR programs have been conducted. The most elaborate research so far was commissioned by the Federal Office for Spatial Development (ARE, 2006), where simple simulations were used to investigate the influence of different TDR settings on land and real estate markets, as well as their spatial and social impacts (for a critical discussion see Zollinger (2006)).

Further discussions about TDR programs in Switzerland are to be found in Gmünder (2004, 2010), Süess and Gmünder (2005), and Zollinger and Seidl (2005). These first studies are all merely conceptual, and no calculations or simulations were undertaken.

Hence, chapter 2 (first paper) presents an improved TDR concept related more to the specific Swiss spatial planning situation and including the decision-making by potentially involved agents.

The proposed concept is designed as a so-called dual-zone program with both a ‘sending’ and a ‘receiving area’ (cf. Fig. 2-3). In this concept, landowners in so-called ‘sending areas’ (here: municipality A) can sell their right to develop a parcel to landowners in ‘receiving areas’ (here: municipality B). The former are regions (land parcels) in which there is no or little demand for it or where building activities should be prevented in accordance with existing Swiss spatial planning principles; the latter are land parcels not designated as building zones, which, however, in accordance with Swiss spatial planning principles, should be developed in the future due to high demand.

The TDR market price represents a compensation for the loss of benefits caused by downzoning of parcels in the sending area. TDR trade is managed by a ‘TDR bank’, which acts as buying and selling mediator and provides a market platform.

The exchange of the development opportunities (TDR) has two major advantages: the overall building zone area will be reduced as there might be denser development in the receiving area compared to the density in the sending area, or the building zone will at least remain the same. A precondition is setting a cap for new building zones. Moreover, the development costs for the society could be reduced because the receiving area – compared with the sending area – consists of parcels that can be more easily provided with infrastructure (e.g. streets, electricity, water) and connected to public transport.

Simulation of the TDR market

The proposed TDR market model (TDR-ABM) simulates the trading of multiple units of TDR at fixed package sizes. It distinguishes two agent types representing landowners who submit asks (called sender agents or senders; divided into subcategories, see below) or bids (called receiver agents or receivers; divided into subcategories, see below) for TDR, and one agent type for the TDR exchange platform (called trading agent).

The simulated trading follows the rules of a multi-unit double auction with a uniform price and works as follows: Each sender who is willing to participate in the TDR market submits an ask with the desired price per TDR (willingness to accept), and each potential receiver participating in the market submits a bid with the price he is willing to pay for the needed TDR (willingness to pay).

After the submission of all the asks and bids, that is at the end of the trading period (representing one year), the trading agent calculates the market clearing price. For this calculation, the asks are sorted by price in ascending, the bids in descending order. The market clearing price is the price at the intersection of the ask- and bid-curves.

Successful traders are the senders with an ask price below or equal the market clearing price and the receivers with a bid price above or equal the market clearing price. The unsuccessful market participants have the opportunity to participate in the next auction – probably with adapted ask- respectively bid-prices. For the proposed Swiss scheme it is suggested running two rounds of five auctions, with one year between each auction. The total time required to organize five auctions (=5 years) gives municipalities time to adapt their zoning plans, i.e. designate sending and receiving areas, for the next round. Moreover, the municipalities can designate sending and receiving areas at given intervals. This should prevent a rampant building boom in the receiving area, which should keep the supply and demand in balance. The main reasons to conduct an auction only once a year are threefold: First, traders will be encouraged to bid more truthfully because it would take a long time until the next trading opportunity[34]. Second, according to Evans and Peck (2007) the market participants need to have enough time to generate the necessary information for their asking/bidding strategy. Third, a result of two

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[34] Note that following the questionnaire after the five auctions – independent of the participation of the landowners – the parcels in the sending area will be downzoned. Therefore, there are no financial options other than trying to sell the assigned TDR as a compensation for the loss of the development opportunity. Nevertheless, because of possible wishful thinking, there are still respondents who are not willing to participate in the TDR market (cf. section 3.3.2 for reasons for not participating in the TDR market). Also, for the landowners in the receiving area there is no other options than trying to buy TDR, in the case they want to develop their parcel. Moreover, at the end of the TDR program (e.g. 90% of the total TDR quantity is sold), it is suggested to replace the TDR program with a TPP program (Tradable Planning Permits, cf. e.g. Henger and Bizer, 2010). In such a follow-up program, a political body (e.g. the Swiss Federal Office for Spatial Development) would define a predetermined total permit quantity of TPP for designating new building zones. This total quantity could be distributed – according to a defined distribution formula – to the municipalities which could then trade the TPP amongst each other.

expert workshops[35] was that the time between auctions should be approximately equal to the time required to plan a housing project.

The sender respectively receiver agents are subdivided into four different landowner categories (cf. Table 3-2 and Table 3-3) assuming each category behaves differently[36]. The subdivision into the different categories was done according to existing land registry data of various municipalities in the Canton of Grisons, and according to transaction data of undeveloped land parcels of the Cantons of Zurich and Fribourg. The identified categories were large enough to enclose a sufficient number of actors and to keep the modeling tractable, but detailed enough to allow for fundamental differences in priorities.

To gather realistic data, we conducted a questionnaire survey based on the following research questions: (1) Do the landowner categories participate in the TDR market with different probabilities? (2) What are the most important criteria when determining the TDR price and is there a difference between the landowner categories? (3) What are the reasons for not participating in the TDR market and is it dependent on the landowner characteristics (e.g. experience in land sale or purchase)? (4) Which variables (e.g. parcel area) determine the TDR price in the first auction (ask and bid price) and (5) do the four landowner categories behave differently? (6) Does the location factor have an influence on the price that a landowner asks or pays for the whole TDR bundle[37] of a certain parcel? (7) What is the adaptation of the TDR price during the proposed five auctions and is there a difference in the adaptation between the landowner categories?

To address these questions we analyzed the data with descriptive statistics (cf. section 3.3.2) and with analytical statistics methods (e.g. regression analysis; cf. section 3.3.3).

3.1.3 Empirical data – a challenge in ABM

Approaches to gain and integrate empirical data

One of the main challenges in agent-based modeling is to simulate individual decision-making. For example, it is often difficult to consider the impacts of risk aversion, learning abilities, and the degree of individual rationality toward market prices and quantities (Chan et al., 1999; Bădică et al., 2006). Furthermore, there is no simple method or solution for determining how agents process information and derive their trading rules. Consequently, there is no assurance that any single result is not just an artifact of the particular subjects and context. Moreover, the complexity of human behavior forces

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[35] The auction design (number of auctions, time between the auctions etc.) has been defined and elaborated in two expert workshops: one with spatial planning and real estate experts (participants were experts from local authorities, banks, real estate companies, a planning association and academics), and one with auction design specialists.

[36] Because of the low response in the category of cooperatives, we merged this category to the category of confederation/canton/municipality (non-profit institutions).

[37] By 'TDR bundle' we mean the total number of TDR per parcel.

agent-based modelers to seek approaches that refine and extend existing theories about human decision-making (Chan et al., 1999).

There exist several approaches and methods to calibrate ABM (see below for the difference between direct and indirect calibration) or in other words combine ABM with empirical data. Janssen and Ostrom (2006) provide an overview about various methods to gather empirical data for ABM. They distinguish four categories of empirical approaches to gather empirical data to inform agent-based models. These are: case studies, stylized facts, role-playing games, and laboratory experiments. Each of these approaches has advantages and disadvantages. Whichever approach one chooses depends on different aspects, like e.g. data availability, time, financial resources, and most importantly on the goal of the study.

We gathered and combined empirical data generated by a survey to inform an agent-based model (TDR-ABM), which, according to the categories of Janssen and Ostrom (2006), belongs to the category of case studies[38]. Combining a survey with an agent-based model is a common approach and there are numerous examples (cf. e.g. Brown and Robinson, 2006; Kaufmann et al., 2009; Schwarz and Ernst, 2009 or Feola et al., 2011). Alternative approaches to obtain the necessary information would have been a role-playing game or an economic experiment. However, the former would have been too time-consuming and costly, particularly because participants from all over Switzerland would have had to be gathered. The latter approach was not suitable because an experiment would not have allowed the representation of such a complex topic as a TDR trade.

So far there is no ABM for TDR and thus no empirical study to gather data for ABM. However, a survey on TDR is known, namely that of Conrad and LeBlanc (1979). Due to the temporal distance, the small representative value (sample size = 22), and the survey within a different planning system compared to the Swiss one, we cannot use the results.

Using a survey to calibrate an ABM for a TDR market is particularly challenging because (a) so far respondents have no experience with TDR, (b) the mechanisms of a TDR market are rather complex to explain and to understand, which is a particular challenge for a written survey, and (c) although the situation is hypothetical, the questions have to be presented as realistically as possible.

Direct calibration of the TDR-ABM with survey data

In order to calibrate the TDR-ABM, we conducted a survey among representatives (professionals) of different landowner categories (cf. Table 3-2). The aim of the survey was to collect data about the behavior of the different landowner categories which could then be used to inform the TDR-ABM (cf. Table 3-1 for more details about the calibrated parameters). According to Schwarz and Ernst (2009)

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[38] According to Janssen and Ostrom (2006) in case studies, the researcher can combine information from different sources, such as remote sensing, surveys, census data, field observations, etc..

this type of calibration is known as direct calibration. A model is directly calibrated when empirically derived data are used as values for model parameters or initial calibration. Here, the empirically derived data to inform the TDR-ABM can be divided into two groups: The first group represents parameters gained with the survey and used without additional econometric calculation (p_{send} and $p_{receive}$, cf. Table 3-1), the second group stands for parameters that are econometrically calculated values (parameters used for determining the TDR price and the TDR price adaptation functions, cf. Table 3-1). The latter parameter group introduces an additional statistical uncertainty.

In contrast, in an indirectly calibrated model empirical data would be compared to model outputs. The chosen model parameters would be determined in a way that the model replicates the empirical data best.

For the TDR-ABM, indirect calibration was not feasible for two reasons: First, empirical data for model outcomes are not available for the completely new concept of TDR in Switzerland. Second, in an indirectly calibrated model many parameter combinations could lead to the same output (Schwarz and Ernst, 2009).

3.2 Methods

3.2.1 Chosen survey type and development of the questionnaire

According to Häder (2010), the choice of a survey method is mainly driven by the extent of standardization, the possible types of contact and the number of respondents one wants to reach with the survey. A basic distinction is made between personal, telephonic, mail and web based surveys. Each of these methods has advantages and disadvantages, and there is no ideal method. The most appropriate survey type can only be found by an evaluation of the pros and cons of a method to reach a certain goal (Dillman et al., 2009; Häder, 2010).

Based on these specifics, we analyzed our objective and choose to conduct a mail and web based survey among persons, qualified in the field of spatial planning and real estate (called ‘professionals’ in what follows) (cf. section 3.2.2). Professionals were chosen instead of a random sample of all existing and potential landowners, because of the complex topic of transferable development rights, the lack of any public information and debate about this instrument which might have made the questionnaire too difficult for the general public; rather it would be an advantage to have previous knowledge in spatial planning and real estate. Also the professionals would be a large part of participants in a TDR market either because they or their institutions would be involved or because they would represent participants of the general public.

The survey was conducted in the form of a questionnaire combining various social theory elements, that is qualitative and quantitative elements, to benefit from the advantages of the different methods.

A purely qualitative survey (e.g. in form of interviews) was not chosen, because this would have led to an explorative survey without useful statistical results for implementing in the TDR-ABM. In our case, we had previous knowledge on TDR from existing academic discussion and our own exchange with experts and therefore, an explorative survey was not needed. Some qualitative elements were introduced, e.g. in questions with an open or semi-open answer possibility to allow the respondents to answer some questions with their personal views and ideas. These answers cannot be statistically assessed, but provide additional information about TDR. Moreover, the open and semi-open response categories are an incentive for the respondents to give answers, as they offer an additional and sometimes easier possibility to express their opinions (Dillman et al., 2009).

The quantitative and statistically evaluated elements were the questions with standardized answer possibilities and the questions in which we ask to valuate (price indication) the TDR. The latter were questions that can be categorized as contingent valuation method (CVM) questions (cf. e.g. Mitchell and Carson, 1993).

Each single questionnaire stated a unique realistic situation description that suited the contacted landowner category. The numbers and details (e.g. parcel area, location etc.) for these descriptions were derived from the above mentioned land registry data and transaction data of undeveloped land parcels (building and agricultural zones).

For example, a respondent contacted as a possible landowner in the receiving area was confronted with the stated situation that he owns a certain parcel with some properties[39]: e.g., location (municipality type) = rich municipality, parcel area = 600 m^2, utilization factor[40] = 0.3, required number of TDR to develop the parcel[41] = 180, land price in the building zone (before introduction of the TDR market) = 500 CHF and land price in the agricultural zone = 6 CHF. Besides this situation description, the questionnaire gave the details about the price formation mechanism in the TDR market, which were about the proposed double auction (cf. section 3.1.2, sub-section *Simulation of the TDR market*). Then, after the background information, the respondents had first to answer if they would participate in the TDR market or not. In the case that they decided to participate they were asked about their TDR price (asks or bids for the 5 auctions) and their criteria for determining the TDR price. In addition, the re-

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[39] The given values in the questionnaire covered the following range: parcel area (in sqm): 400 to 1,900; utilization factor: 0.3 to 0.5; building zone price (in CHF per sqm): 60 to 2,760; agricultural zone price (in CHF per sqm): 3 to 6.

[40] The utilization factor *UF* determines – together with the parcel area – the legally allowed floor area per building zone parcel and thus the quantity of TDR per parcel.

[41] The number of TDR per parcel is defined as a multiplication of the parcel area and the utilization factor. An optional location factor might be added additionally in the TDR-ABM.

spondents who represented a landowner in the receiving area were asked about their price expectations (WTP) for the given parcel without TDR.

The respondents who decided not to participate in the TDR market were asked about their reasons. At the end of the questionnaire, we asked personal questions as e.g. the ‘age group’ or ‘experience in land purchase or sale’.

We performed a pretest with approximately 20 respondents. The final questionnaire was mailed in January and March 2012 (languages: German and French) with the additional possibility to fill it out online[42]. The questionnaire was mailed twice because of the insufficient response rate (17.22%) in the first survey round. The final response rate was 16.75%[43] (cf. section 3.3.1), however, the overall absolute number of respondents (n=331) was sufficient to carry out statistical models.

Overall, the questionnaire was considered to be complex and demanding. Yet, the time needed to understand and fill out the questionnaire should not have exceeded 20 minutes. Table 3-1 gives an overview about the collected information and the herewith calibrated parameters of the TDR-ABM.

Table 3-1: Collected information and parameters to be calibrated.

Collected information	**Parameters/functions[a] of the TDR-ABM**
Willingness/Probability to participate in the TDR market	Parameters p_{send} resp. $p_{receive}$
Initial (first auction) ask resp. bid price	Ask resp. bid price initialization function parameters
Ask resp. bid price adaptation during the five auctions	Ask resp. bid price adaptation function parameters
Influence of the location on the TDR price	Location factor *LF*
Price for the land without TDR	Not yet integrated into the simulation, but useful for further improvements of the TDR-ABM
Criteria for valuation of the TDR	Not yet integrated into the simulation, but useful for further improvements of the TDR-ABM
Reasons for not participating in the TDR market	Not yet integrated into the simulation, but useful for further improvements of the TDR-ABM
Personal data of the respondents (representing sender and receiver agents)	Not yet integrated into the simulation, but useful for further improvements of the TDR-ABM

[a] The mentioned parameters and functions are described in detail in chapter 2 and 4.

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[42] The URL of the webpage and login-details were listed on the cover letter of the questionnaire.

[43] The slightly lower response rate may be explained by the address database used which was bought form a professional address seller. In the first survey round addresses from engaged members from the planning and real estate sector were used.

3.2.2 Contacted professionals

A total of 1,976 professionals in all of Switzerland were contacted. These people were contacted to represent either landowners in the sending or receiving area. Their personal characteristics are represented in Table 3-2.

Among the contacted professionals, four different landowner categories were distinguished, and each category was subdivided into two equal parts, one part representing 'senders' (suppliers) and one representing 'receivers' (demanders) of TDR.

The addresses came from different sources based on our own research mainly of addresses of municipalities, the address list of an event of cooperatives, address lists of spatial planning and real estate events, the address list of alumni in spatial planning, the address list from the CD 'who is who in the Swiss real estate industry', and addresses from a professional address seller.

The special landowner structure in Switzerland was one of the main reasons for the different number of contacted professionals between the four categories (cf. Table 3-3). For example, the statistical analysis of the land registry and transaction data (cf. section 3.1.2, sub-section *Simulation of the TDR market*) has shown that on average about 66% of the land in the building zone (here: residential zone) is owned by private persons, 19% by enterprises, 11% by the state (municipalities, cantons and confederation), and 4% by cooperatives and other social organizations (e.g. associations). These proportions vary considerably depending on the type of municipality[44]. Another reason for the different number of contacted respondents was that the number of professionals in the different categories varies.

Table 3-2: Personal characteristics of the respondents.

	Enterprises[a] operating in commercial real estate transaction		**Confederation/ Canton/ Municipality**		**Architects and Real Estate developers[b]**		**Cooperatives**	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Language								
German	56	93.3%	88	81.5%	124	88.6%	23	100.0%
French	4	6.7%	20	18.5%	16	11.4%	0	0.0%
Age group (years)								
20 - 35	3	5.0%	8	7.4%	16	11.4%	1	4.3%
36 - 50	23	38.3%	47	43.5%	57	40.7%	8	34.8%
> 50	32	53.3%	49	45.4%	63	45.0%	12	52.2%
n/a	2	3.3%	4	3.7%	4	2.9%	2	8.7%

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[44] For example, land owned by private persons varies from 28% in tourism municipalities to 90% in commuter municipalities outside urban areas.

Experience in land purchase or sale (years)								
< 5	7	11.7%	39	36.1%	37	26.4%	4	17.4%
5 - 9	5	8.3%	16	14.8%	11	7.9%	5	21.7%
10 - 14	10	16.7%	16	14.8%	22	15.7%	2	8.7%
15 - 19	6	10.0%	5	4.6%	8	5.7%	4	17.4%
20 - 24	8	13.3%	15	13.9%	21	15.0%	3	13.0%
> 25	23	38.3%	13	12.0%	38	27.1%	4	17.4%
n/a	1	1.7%	4	3.7%	3	2.1%	1	4.3%
Previous concern with TDR								
No	40	66.7%	69	63.9%	69	49.3%	19	82.6%
Somewhat	13	21.7%	29	26.9%	56	40.0%	3	13.0%
Yes	5	8.3%	10	9.3%	12	8.6%	0	0.0%
n/a	2	3.3%	0	0.0%	3	2.1%	1	4.3%
Difficulty completing the questionnaire								
Easy	13	21.7%	18	16.7%	22	15.7%	7	30.4%
Rather simple	27	45.0%	41	38.0%	57	40.7%	10	43.5%
Rather difficult	15	25.0%	34	31.5%	50	35.7%	5	21.7%
Difficult	2	3.3%	6	5.6%	7	5.0%	0	0.0%
n/a	3	5.0%	9	8.3%	4	2.9%	1	4.3%
Interest in survey results								
Yes	42	70.0%	57	52.8%	104	74.3%	6	26.1%
No	9	15.0%	32	29.6%	20	14.3%	6	26.1%
n/a	9	15.0%	19	17.6%	16	11.4%	11	47.8%

[a] Corporation/Limited Liability Partnership/Bank/Insurance Company etc..

[b] It was supposed – and mentioned in the questionnaire – that architects and real estate developers should represent the interests of private persons.

3.3 Results

3.3.1 Response rate and quality of responses

Response rate

As mentioned above, the overall response rate of the survey was 16.75%. We assessed the response burden according to the calculation in Axhausen and Weis (2010) and obtained a value of around 60 points. For surveys with such a response burden, Axhausen and Weis (2010)[45] would predict a response rate of over 20%. The low response rate might be explained in two ways. First by the existing scepticism towards TDR. Gmünder (2010) found in his survey that among the environmental economic spatial planning instruments, TDR have a low level of political acceptance. He explains this as the result of very little information and public discussion about this instrument. The second explanation may be the long and challenging introduction to the questionnaire (2.5 pages), explaining the instru-

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[45] Axhausen and Weis (2010) analyzed surveys conducted at the Institute for Transport Planning and Systems, ETH Zurich.

ment and how to fill out the survey, which probably led potential respondents to ignore the questionnaire. This fact could not be considered in the response burden assessment.

Table 3-3: Contacted professionals and response rate of the different landowner categories.

Landowner category	**Number of contacted professionals**[a]	**Returned questionnaires (senders)**	**Returned questionnaires (receivers)**
Enterprises operating in commercial real estate transaction *(called hereinafter 'enterprises')*	489	35 14.3%	25 10.2%
Confederation/Canton/Municipality *(called hereinafter 'non-profit institutions', abbreviated 'NPI')*	502	54 21.5%	54 21.5%
Architects and Real Estate developers *(called hereinafter 'representatives of private persons', abbreviated 'RPP')*	829	80 19.3%	60 14.5%
Cooperatives *(merged hereinafter with the category of 'NPI')*	156	12 15.4%	11 14.1%
Overall	1,976	181 18.3%	150 15.2%

[a] The contacted professionals were divided in two equal parts: one part had to answer as sender, the other as receiver.

Among the contacted landowner categories (cf. Table 3-3), NPI and RPP were slightly more willing to fill out the questionnaire than other categories. However, the differences between the categories are too small to be significant.

Because of the small number of respondents in the category of cooperatives, and the fact that a majority of those respondents was not willing to participate in the TDR market, we merged the cooperatives and the category of NPI for the following calculations.

Quality of responses – plausibility test

Because of the complex topic, the demanding questionnaire and the missing public information about TDR we compared the stated prices (asks and bids) with the theoretically expected TDR value (here defined as rational behavior) to test whether responses are reliable:

$$PTDR_{theoretical} = (PBuildZone - PAgrizone)/UF \qquad (3\text{-}1)$$

where *PBuildZone* represents the building zone price, *PAgrizone* the agricultural zone price and *UF* the utilization factor *UF* (cf. footnote 40).

The consideration behind this plausibility test is that, when the price of agricultural land is given to be 6 CHF/m^2, the price of building zone land to be 500 CHF/m^2 and $UF = 0.3$, this means that 0.3 TDR are needed to transform land worth 6 CHF into land worth 500 CHF, so the TDR might be worth

494/0.3 = 1650 CHF[46] ($PTDR_{theoretical}$). Note that the given prices of agricultural and building zone land are just points of reference – as in a real world people would refer to market prices – and not the prices for an outside-option.

Based on the above, we assumed that a response/questionnaire is reliable and realistic if the stated ask price in the first auction is greater than 0.5 of the theoretical TDR value while the corresponding stated bid price in the fifth auction is greater than 0.3 of the theoretical TDR value[47].

The criteria of the plausibility test were defined according to the statistical distribution of the stated prices in comparison to the theoretical TDR value (cf. Fig. B-1 and Fig. B-2 in the appendix B), and were of tantamount important because of other responses that further indicated misunderstanding of the questionnaire (e.g. high difficulty in completing the questionnaire combined with unrealistically high/low prices, little experience in land purchase or sale combined with unrealistically high/low prices, etc.).

All responses that did not fit the mentioned criteria were classified as not plausible (outliers) and they indicate that (a) the respondent did not correctly understand the questionnaire or (b) the respondent gave no effort in answering the questionnaire. As a result, we exclude for the following descriptive and analytical results 20 questionnaires of senders (3 of the category of enterprises, 5 NPI and 12 RPP) and 15 of receivers (2 of the category of enterprises, 4 NPI (incl. cooperatives) and 9 RPP). The resulting number of observations is n=124 (only respondents that stated they would participate in the TDR market).

3.3.2 Descriptive statistics results

In this section we present the results of the descriptive statistical analysis. The results of analytical statistical analysis including the prices that were stated in the questionnaire survey are reported in section 3.3.3.

Participation per landowner category

In the first question we asked the respondents whether they would participate in a TDR market or not[48]. The corresponding results for the senders and receivers are illustrated in Table 3-4[49].

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[46] In the questionnaire this calculation was presented in a simple way for participants because the total value of the parcel without and with TDR was indicated as well as the number of TDR needed. The indicated prices were realistic values (cf. section 3.2.1) for the described situation.

[47] Since the participants could think strategically and ask high or bid low prices in the first auctions, we assumed that just the first ask respectively fifth bid price should hold the mentioned criteria. However, strategic behavior was only considered to be realistic in the case that the stated prices were not greater than 5 times the theoretical TDR value.

[48] Not to be confused with the general participation in the survey, which was described in section 3.3.1.

[49] The participation probability results before the exclusion of possible outliers can be found in the appendix B (Table B-1).

Among the senders, it is striking that NPI are barely ready to sell. The reason may be that this category owns few land reserves (especially cooperatives) in the building zone and they do not want to give up any potential development opportunity.

Moreover, the numbers in Table 3-4 indicate that NPI are also hardly willing to buy any development rights. The possible reasons may be that NPI are either skeptical towards TDR or feel buying TDR is an undertaking for enterprises and RPP.

The highest willingness to participate is found, for both senders and receivers, in the category of RPP. It might be that RPP rely less on strategic considerations than other landowner categories and therefore the willingness to participate is higher. More information about the reasons for not participating in the TDR market is presented below (sub-section *Reasons for not participating in the TDR market*).

Table 3-4: Sender and receiver participation probability per landowner category.

Landowner category		**Sender Participation**		**Receiver Participation**	
		Yes	**No**	**Yes**	**No**
Enterprises	Number	15	17	12	12
	Percent	46.9%	53.1%	50.0%	50.0%
NPI	Number	18	43	10	50
	Percent	29.5%	70.5%	16.7%	83.3%
RPP	Number	38	30	31	20
	Percent	55.9%	44.1%	60.8%	39.2%
Overall	Number	71	90	53	82
	Percent	44.1%	55.9%	39.3%	60.7%

TDR valuation criteria

The respondents who stated they would participate in the TDR market were asked – after they stated their price expectations (bid resp. ask price; cf. section 3.3.3) – about their criteria when determining the value of the TDR of the given parcel. Table 3-5 and Table 3-6 summarize the results for the senders and receivers.

It is striking that, following the responses, the ‘building zone price before introduction of TDR’ is for both senders and receivers particularly important. The other criteria have been – apart from the ‘price for agricultural land’ and ‘other criteria’ – rated quite similarly between the categories.

Table 3-5: Sender's criteria when determining the TDR price (more than one answer possible).

Criteria		Enterprises	NPI	RPP
Price agricultural land	Number Percent	3 7.3%	3 6.7%	6 5.8%
Building zone price before introduction of TDR	Number Percent	13 31.7%	13 28.9%	34 32.7%
Expected loss in value due to "non-development"	Number Percent	7 17.1%	8 17.8%	20 19.2%
Location quality (e.g. peripheral location)	Number Percent	6 14.6%	7 15.6%	13 12.5%
Compensation of the expenses to date	Number Percent	3 7.3%	6 13.3%	8 7.7%
Need/desire to develop the parcel (e.g. for own use)	Number Percent	7 17.1%	3 6.7%	10 9.6%
Interest in immediately downzoning the parcel	Number Percent	1 2.4%	2 4.4%	4 3.8%
Other criteria[a]	Number Percent	1 2.4%	3 6.7%	9 8.7%
Overall	Number Percent	41 100%	45 100%	104 100%

[a] ‚Other criteria' given by the respondents were e.g. 'long-term shortage of building zone area'.

Table 3-6: Receivers's criteria when determining the TDR price (more than one answer possible).

Criteria		Enterprises	NPI	RPP
Price agricultural land	Number Percent	5 11.6%	4 13.3%	11 9.8%
Building zone price before introduction of TDR	Number Percent	9 20.9%	6 20.0%	20 17.9%
Expected increase in value through the acquisition of TDR/expected return	Number Percent	8 18.6%	3 10.0%	19 17.0%
Location quality (e.g. good public transport connections)	Number Percent	10 23.3%	6 20.0%	21 18.8%
Need/desire to develop the parcel (e.g. for own use)	Number Percent	2 4.7%	5 16.7%	10 8.9%
Own financial situation	Number Percent	7 16.3%	5 16.7%	22 19.6%
Other criteria[a]	Number Percent	2 4.7%	1 3.3%	9 8.0%
Overall	Number Percent	43 100%	30 100%	112 100%

[a] Other criteria' given by the respondents were e.g. 'time saving by bypassing lengthy negotiations'.

Reasons for not participating in the TDR market

The respondents who stated they would not participate in the TDR market were asked about their reasons for not participating in the TDR market. For both senders and receivers, two criteria turned out to be essential: the seemingly too complicated procedure of the TDR instrument and the high transaction costs. Other reasons given by the respondents included ‘intervention in the property rights‘ (sender), ‘encouragement of land speculation’ (sender and receiver), ‘TDR as a competition distorting instrument’ (sender and receiver) or ‘TDR as a price-raising instrument’ (receiver).

It is worth stating at this point that the responses against participating in the TDR market must be regarded with caution given the way the problem was described in the questionnaire, not participating amounts to burning money. Hence, here not participating may also be understood either (a) as a general opposition against such an instrument, (b) as the expression of expectations that the ‘rules of the game’ would change in the future, for example regarding new zoning practices (‘wishful thinking’), hence participating now may not actually mean missed opportunities, or (c) as evidence that the ‘rules of the game’ were not understood.

Correlation of personal characteristics and TDR market participation

To investigate whether the participation probability is dependent on the respondents' characteristics, we calculated the correlation[50] between these variables. Table 3-7 shows that there is no strong correlation between the variables.

Table 3-7: Correlation of the TDR market participation and personal characteristics[a].

	Age group	**Experience in land purchase or sale**	**Previous concern with TDR**	**Difficulty completing the questionnaire**	**Interest in survey results**
Participation	-0.171**	-0.156**	-0.120*	0.265**	0.221**

[a] Spearman-Rho Correlation. Significance levels (two-tailed): ** 1%, * 5%

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[50] We choose to calculate the Spearman Correlation coefficient, because – compared to the Pearson coefficient – no linear relationship is postulated.

3.3.3 Analytical statistics results

Data used for the analytical models

For the analytical statistical models we could only use data of respondents who agreed to participate in the TDR market and data that was classified as 'reliable' (n=124) (cf. section 3.3.1).

Because we assume that respondents asking high prices (bidding low prices) in the first auction might decrease (increase) their prices in the subsequent four auctions more than other respondents, we calculate a variable '*AdaptationRate'* that considers this behavior (eq. 3-2 for senders, eq. 3-3 for receivers):

$$AdaptationRate = (P_{Ask1} – P_{Ask5}) / (P_{Ask1}) \qquad (3\text{-}2)$$

$$AdaptationRate = (P_{Bid5} – P_{Bid1}) / (P_{Bid1}) \qquad (3\text{-}3)$$

where P_{Ask1} (P_{Bid1}) represents the ask (bid) price in the first auction and P_{Ask5} (P_{Bid5}) the ask (bid) price in the fifth auction.

The descriptive statistics of the data used in the analytical models for both senders and receivers are illustrated in the Table 3-8 to Table 3-13.

Sender

Table 3-8: Descriptive statistics of the data used in the analytical models for senders of the category of enterprises.

Variable name	**Description**	**Minimum**	**Maximum**	**Mean**	**S.D.**
P_{Ask1}	Ask price per TDR in the first auction (in CHF)	487.50	2,500.00	1,295.04	602.30
P_{AskLF}	Ask price per TDR – calculated with the location factor – in the first auction (in CHF)	100.00	3,500.00	1,356.92	872.10
ParcelArea [a]	Parcel area (in qm)	600.00	1,600.00	1,120.00	275.68
LocationFactor [b]	Land price index	0.87	1.18	0.97	0.10
$PTDR_{theoretical}$	Theoretical TDR value (in CHF)	487.50	1,860.00	1,023.22	371.64
AdaptationRate	Adaptation of the TDR price (first to fifth ask price)	0.00	0.82	0.24	0.22

[a] values for these variables were given in the questionnaire.

[b] The location factor represents a land price index at municipality level (for building zones) and so it takes into account the very different land prices of the various building zones areas.

Table 3-9: Descriptive statistics of the data used in the analytical models for senders of the category of NPI.

Variable name	**Description**	**Minimum**	**Maximum**	**Mean**	**S.D.**
P_{Ask1}	Ask price per TDR in the first auction (in CHF)	650.00	3,200.00	1,441.67	671.77
P_{AskLF}	Ask price per TDR – calculated with the location factor – in the first auction (in CHF)	500.00	3,070.00	1,396.47	687.70
ParcelArea [a]	Parcel area (in qm)	450.00	1,350.00	1,016.67	237.64
LocationFactor	Land price index	0.91	1.30	0.99	0.09
$PTDR_{theoretical}$	Theoretical TDR value (in CHF)	735.00	2,553.33	1,167.45	465.51
AdaptationRate	Adaptation of the TDR price (first to fifth ask price)	0.06	0.90	0.38	0.25

[a] values for these variables were given in the questionnaire.

Table 3-10: Descriptive statistics of the data used in the analytical models for senders of the category of RPP.

Variable name	**Description**	**Minimum**	**Maximum**	**Mean**	**S.D.**
P_{Ask1}	Ask price per TDR in the first auction (in CHF)	450.00	3,313.00	1,505.83	798.58
P_{AskLF}	Ask price per TDR – calculated with the location factor – in the first auction (in CHF)	400.00	2,600.00	1,390.17	605.73
ParcelArea [a]	Parcel area (in qm)	450.00	1,250.00	815.80	308.90
LocationFactor	Land price index	0.87	1.27	1.02	0.12
$PTDR_{theoretical}$	Theoretical TDR value (in CHF)	612.50	3313.33	1372.96	763.25
AdaptationRate	Adaptation of the TDR price (first to fifth ask price)	0.00	0.99	0.40	0.26

[a] values for these variables were given in the questionnaire.

Receiver

Table 3-11: Descriptive statistics of the data used in the analytical models for receivers of the category of enterprises.

Variable name	Description	Minimum	Maximum	Mean	S.D.
P_{Bid1}	Bid price per TDR in the first auction (in CHF)	400.00	1,875.00	916.08	479.25
P_{BidLF}	Bid price per TDR – calculated with the location factor – in the first auction (in CHF)	450.00	1,875.00	932.75	442.57
ParcelArea [a]	Parcel area (in qm)	900.00	1,700.00	1,304.17	227.10
LocationFactor	Land price index	0.92	1.31	1.13	0.12
$PTDR_{theoretical}$	Theoretical TDR value (in CHF)	860.00	2,860	1,714.58	624.32
AdaptationRate	Adaptation of the TDR price (first to fifth bid price)	0.15	2.49	0.73	0.65

[a] values for these variables were given in the questionnaire.

Table 3-12: Descriptive statistics of the data used in the analytical models for receivers of the category of NPI.

Variable name	Description	Minimum	Maximum	Mean	S.D.
P_{Bid1}	Bid price per TDR in the first auction (in CHF)	100.00	1,700.00	640.00	469.52
P_{BidLF}	Bid price per TDR – calculated with the location factor – in the first auction (in CHF)	100.00	1,800.00	617.00	493.33
ParcelArea [a]	Parcel area (in qm)	850	1,550	1,180.00	266.88
LocationFactor	Land price index	0.87	1.20	1.02	0.12
$PTDR_{theoretical}$	Theoretical TDR value (in CHF)	737.50	5,186.67	1,585.08	1,331.92
AdaptationRate	Adaptation of the TDR price (first to fifth bid price)	0.40	1.50	0.86	0.34

[a] values for these variables were given in the questionnaire.

Table 3-13: Descriptive statistics of the data used in the analytical models for receivers of the category of RPP.

Variable name	Description	Minimum	Maximum	Mean	S.D.
P_{Bid1}	Bid price per TDR in the first auction (in CHF)	196.65	2,500.00	965.18	624.60
P_{BidLF}	Bid price per TDR – calculated with the location factor – in the first auction (in CHF)	210.70	1,900.00	934.09	541.27
ParcelArea [a]	Parcel area (in qm)	450.00	1,200.00	769.35	308.94
LocationFactor	Land price index	0.86	1.31	1.07	0.15
$PTDR_{theoretical}$	Theoretical TDR value (in CHF)	492.50	2,860.00	1499.22	688.75
AdaptationRate	Adaptation of the TDR price (fifth minus first bid price divided by the first bid price)	0.08	4.00	0.78	0.77

[a] values for these variables were given in the questionnaire.

Regression models without interactions

In order to investigate the research questions 4 to 7 (cf. section 3.1.2), we calculated various regression models[51] to explain the stated bid and ask prices (cf. Table 3-8 to Table 3-13 for the descriptive statistics of the explanatory variables[52]).

Since the land registry and transaction data used in the TDR-ABM do not include any information on the personal characteristics of the landowners, these variables are not considered in the regression models.

Sender

The first three models for senders (MOD SE, SNPI, SRPP; one model per landowner category) were based on the assumption that the stated ask price in the first auction is a linear function of the theoretical TDR value (cf. eq. 3-1) and other plausible explanatory variables (except for the *LocationFactor*).

Because of our small data set and the fact that our sample cannot be considered as fully representative for the whole population, we kept explanatory variables in our models that were not statistically significant. The reason is that for the calibration of the TDR-ABM we wanted to estimate a model with the highest possible explanatory power. Moreover, the coefficients are less biased, when many control variables are used. They are more accurate, independent of their statistical significance.

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[51] The unknown parameters were estimated with the ordinary least squares (OLS) method.

[52] Also known as ‘independent variables’.

In order to check for multicollinearity we calculated the variance inflation factor (VIF) for the explanatory variables. The VIF values (max. 1.293 for $PTDR_{theoretical}$ in the model MOD SNPI) indicate that no multicollinearity exists.

Table 3-14: Determinants of first ask price of enterprises (MOD SE)[a].

	MOD SE			
Variable name	Coefficients	t-values	Lower level of 95% confidence interval	Upper level of 95% confidence interval
Constant	1332.165*	2.040	-123.089	2,787.419
ParcelArea	-1.018*	-2.029	-2.136	0.100
$PTDR_{theoretical}$	1.075***	3.163	0.318	1.832
AdaptationRate	-154.678	-0.252	-1,523.737	1,214.381
Number of observations	15			
R^2	0.557			
Adjusted R^2	0.424			

[a] Significance levels (two-tailed): *** 1%, ** 5%, * 10%.

Table 3-15: Determinants of first ask price of NPI (MOD SNPI)[a].

	MOD SNPI			
Variable name	Coefficients	t-values	Lower level of 95% confidence interval	Upper level of 95% confidence interval
Constant	956.716	1.487	-423.048	2336.480
ParcelArea	-0.651	-1.149	-1.867	0.564
$PTDR_{theoretical}$	1.090***	3.667	0.453	1.728
AdaptationRate	-333.872	-0.640	-1452.464	784.720
Number of observations	18			
R^2	0.540			
Adjusted R^2	0.442			

[a] Significance levels (two-tailed): *** 1%, ** 5%, * 10%.

Table 3-16: Determinants of first ask price of RPP (MOD SRPP)[a].

	MOD SRPP			
Variable name	Coefficients	t-values	Lower level of 95% confidence interval	Upper level of 95% confidence interval
Constant	198.349	0.999	-205.965	602.663
ParcelArea	-0.025	-0.128	-0.416	0.367
$PTDR_{theoretical}$	0.926^{***}	12.132	0.771	1.082
AdaptationRate	134.163	0.586	-332.026	600.352
Number of observations	38			
R^2	0.826			
Adjusted R^2	0.810			

[a] Significance levels (two-tailed): *** 1%, ** 5%, * 10%.

The results in the Table 3-14 to Table 3-16 show that seemingly all categories asked for prices very close to the theoretical TDR value. The coefficient of this variable is highly significant in all models. However, no statistically significant difference between the categories could be found (confidence levels of the coefficients overlap).

Interestingly, the coefficient of the adaptation rate is not significant and therefore the interpretation should be treated with caution. Yet, because the results for enterprises and NPI are expected, we proceed with an interpretation: if a landowner in the category of enterprises reduces the ask price by 50% (*AdaptationRate* =1) then the ask price in the first auction is 154.7 CHF lower compared to landowners with no adaptation. This means in other words that the greater the adaption rate, the lower the first ask price. In the category of RPP this effect could not be found. However, as the significance tests and the confidence intervals[53] of this coefficient indicate, there are no statistically significant differences between the categories.

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[53] Because of few observations, in particular in the categories of enterprises and NPI, we looked at the residuals of the different models (calculated a QQ-Plot for both sender and receiver models) and found that they correspond to the OLS assumptions (normally distributed). Therefore, we are confident that the data are reliable, and we calculated the confidence intervals of the coefficients. However, because of the small sample size, the interpretation of the confidence intervals should be treated with caution.

The coefficient of the parcel area has a negative sign in all models and points to the fact that respondents with a larger parcel, ask – ceteris paribus – reduced TDR prices. This was expected because the quantity of TDR increases with the parcel area and accordingly, the price for a single TDR decreases (cf. footnote 41).

Receiver

We proceeded in the same way for the receivers (cf. Table 3-17 to Table 3-19). Also here, the multicollinearity check (max. VIF value of 1.680 for *ParcelArea* in the model MOD RE) indicates that no multicollinearity exists.

As expected, the coefficient for the theoretical TDR value is considerably smaller than in the models for the senders. This is due to the fact that the landowners will increase the bid price in the subsequent auctions.

Particularly interesting is that there is a statistically significant difference between NPI and RPP (confidence intervals of $PTDR_{theoretical}$ do not overlap). It is striking that the landowners of the category of NPI bid very low prices in the first auction. This might be connected to a skeptical stance towards a TDR market (low willingness to participate, cf. Table 3-4).

The variable *AdaptationRate* is significant in all categories. Seemingly, market participants in the receiving area behave more strategically than the ones in the sending area. Because of the low value of the coefficient of the theoretical TDR value, NPI adapted the bid price most of all.

The best model – for both senders and receivers – could be estimated for receivers in the category of NPI (MOD RNPI, R^2 of 0.916 and adjusted R^2 of 0.865). Although this result is very promising for the calibration of the TDR-ABM, it should be treated with caution. The sample size of n=10 is too low to be sure that the results are representative for all potential landowners of that category. Concerning the sample size, the most accurate representation could be reached in the category of RPP (for both senders and receivers).

Table 3-17: Determinants of first bid price of enterprises (MOD RE)[a].

	MOD RE			
Variable name	Coefficients	t-values	Lower level of 95% confidence interval	Upper level of 95% confidence interval
Constant	1,561.239*	1.955	-280.239	3,402.718
ParcelArea	-0.954	-1.582	-2.344	0.436
$PTDR_{theoretical}$	0.577**	3.047	0.140	1.013
AdaptationRate	-536.334**	-2.658	-1,001.558	-71.109
Number of observations	12			
R^2	0.611			
Adjusted R^2	0.466			

[a] Significance levels (two-tailed): *** 1%, ** 5%, * 10%.

Table 3-18: Determinants of first bid price of NPI (MOD RNPI)[a].

	MOD RNPI			
Variable name	Coefficients	t-values	Lower level of 95% confidence interval	Upper level of 95% confidence interval
Constant	444.716	1.573	-281.894	1,171.326
ParcelArea	0.445	1.556	-0.290	1.181
$PTDR_{theoretical}$	0.211***	4.298	0.085	0.337
AdaptationRate	-706.460**	-3.372	-1,245.043	-167.878
Number of observations	10			
R^2	0.916			
Adjusted R^2	0.865			

[a] Significance levels (two-tailed): *** 1%, ** 5%, * 10%.

Table 3-19: Determinants of first bid price of RPP (MOD RRPP)[a].

	MOD RRPP			
Variable name	Coefficients	t-values	Lower level of 95% confidence interval	Upper level of 95% confidence interval
Constant	347.590	1.193	-251.109	946.289
ParcelArea	-0.078	-0.280	-0.652	0.496
$PTDR_{theoretical}$	0.596^{***}	5.515	0.374	0.818
AdaptationRate	-263.746^{**}	-2.695	-464.887	-62.605
Number of observations	31			
R^2	0.652			
Adjusted R^2	0.611			

[a] Significance levels (two-tailed): *** 1%, ** 5%, * 10%.

Regression models with interactions

The tested semi-log[54] and double-log models for the senders and receivers did not improve the quality of the previous models. For this reason, the results are not illustrated here.

Next, we tried to improve the models with the introduction of plausible interactions. We considered the following interactions to be plausible: interaction between $PTDR_{theoretical}$ and *AdaptationRate*, $PTDR_{theoretical}$ and *ParcelArea, ParcelArea* and *AdaptationRate*.

However, we found only for the receivers in the RPP category a plausible and significant interaction (*ParcelArea* and *AdaptationRate*) that improved the simple linear model (cf. Table 3-20). The explanation behind this interaction is that the parcel area might have an influence on the adaptation rate. For example, a landowner with a small parcel area might bid more strategically, that is, the adaptation of the bid price during the five auctions might be higher for small parcels.

The structure of the model (MOD RRPP 2) is the same as in the first model (MOD RRPP), except that the interaction has been added. The model quality could be slightly improved (adjusted R^2 from 0.611 to 0.655). The significant effect of the interaction allows the definite statement to be made that if the parcel area increases by one unit, then the coefficient of the variable *AdaptationRate* increases by 0.887. Fig. 3-1 illustrates the marginal effect of the adaptation rate graphically.

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[54] Once we log-transformed the dependent variable and once the explanatory variables (metric variables).

Table 3-20: Determinants of the interaction model of first bid price of RPP (MOD RRPP 2)[a].

	MOD RRPP 2			
Variable name	Coefficients	t-values	Lower level of 95% confidence interval	Upper level of 95% confidence interval
Constant	1048.083**	2.398	147.984	1948.181
ParcelArea	-0.891*	-1.879	-1.868	0.086
$PTDR_{theoretical}$	0.570***	5.551	0.359	0.782
AdaptationRate	-1020.932**	-2.694	-1801.283	-240.581
*AdaptationRate*ParcelArea*	0.887**	2.060	0.000	1.774
Number of observations	31			
R^2	0.702			
Adjusted R^2	0.655			

[a] Significance levels (two-tailed): *** 1%, ** 5%, * 10%.

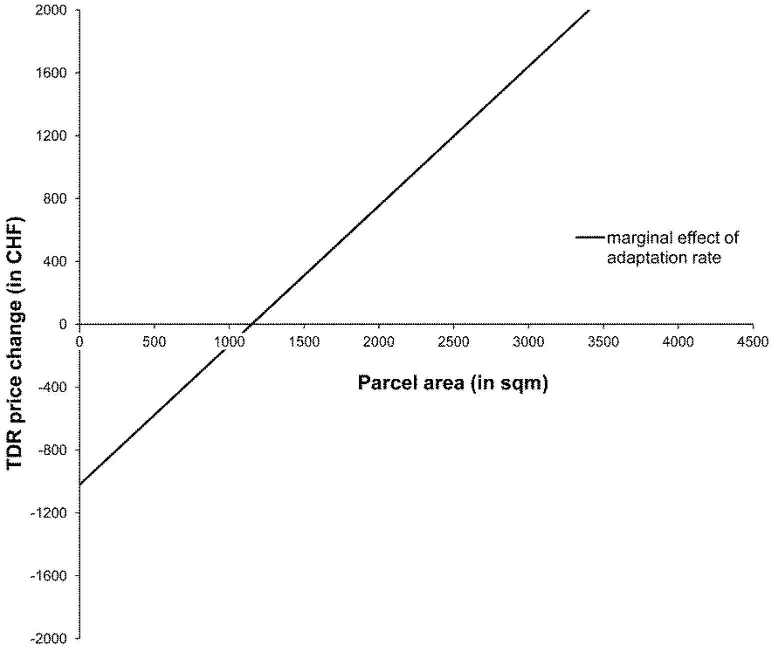

Fig. 3-1: Interaction between adaptation rate (*AdaptationRate*) and parcel area (*ParcelArea*) for receivers of the category of RPP.

Regression models for testing the influence of the location factor

In the TDR-ABM, an additional factor, the location factor, may be introduced which changes the number of TDR per parcel (cf. footnote 41). This factor represents a land price index at municipality level (for building zones) and takes into account the variation of land prices in the building zone areas. By multiplying it with the parcel area and the utilization factor, it reduces (index values below 1) or increases (index values above 1) the number of TDR per parcel.

In the questionnaire we asked the respondents to offer or bid for the TDR of their allocated parcel, once calculated without and once with the location factor. It is assumed that if a landowner considers the value of a parcel as a whole, then the location factor would have no influence (cf. research question 6 in section 3.1.2). This is because they would have a certain idea of how much to ask (bid) for the parcel as a whole and consequently they would ask (bid) more if the number of TDR decreases or ask (bid) less if the number of TDR increases. Hence, in total, the same amount of money per TDR bundle would result.

This research question was addressed through calculating the same regression models as in sub-section *Regression models without interactions* (cf. above), except that the theoretical TDR value has been calculated with the location factor. The corresponding results are listed in detail in the appendix B (cf. Table B-2 to Table B-7).

Most interesting in this analysis was to investigate whether the coefficient for the theoretical TDR value changes or not. The results show that it remained – with very small deviations – the same. As mentioned above, the landowners seemingly have an idea of how much to ask (bid) for the parcel as a whole and consequently they change their ask (bid) prices according to the number of TDR per parcel.

Regression models for estimating the bid and ask price adaptation

In order to estimate the TDR price adaptation during the five auctions we fitted a polynomial function[55] to the stated ask and bid prices. For this purpose, all stated prices were standardized in a way that the first price represents 100% and the prices in the subsequent auctions the respective deviation from 100%.

Sender

The best results for the senders were obtained with linear functions. The form of these functions is described in equation 3-4, and the corresponding coefficients are presented in Table 3-21. Moreover, the Fig. 3-2 to Fig. 3-4 show the adaptation functions with the corresponding confidence levels. The confidence levels have been calculated in order to compare the results of the three categories. Fur-

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[55] The following functions (OLS regression models) were tested with the SPSS ‘curvefit algorithm’: linear, logarithmic, quadratic, cubic, s-shaped and growth-function.

thermore, the stated prices and the respondent-specific adaptations are illustrated in separate figures in the appendix B (cf. Fig. B-3 to Fig. B-5)

In a practical implementation of the TDR-ABM, the functions would be adapted in a way that the price for the first auction equals the determined price in the regression models. This could be easily done through replacing the value of the C*onstant* (here: 100) with the estimated price in the first auction[56].

$$Ask(x) = 100 - b1*x \quad (3\text{-}4)$$

with x=1 for the second ask price, 2 for the third, 3 for the fourth and 4 for the fifth.

Table 3-21: Adaptation functions for senders of different categories.

	R^2	F	p-value	b1	Lower level of 95% confidence interval of b1	Upper level of 95% confidence interval of b1
Enterprises	0.264	24.434	0.000	5.909	4.542	7.277
NPI	0.392	56.707	0.000	9.367	7.948	10.786
RPP	0.423	130.358	0.000	9.780	8.806	10.754

The coefficients (*b1*) in Table 3-21 indicate that the ask price is adapted most (reduced) by RPP, then by NPI and least by enterprises. However, RPP and NPI behave almost equally. They adapt the ask price by 9.8% respectively 9.4% per auction. Enterprises adapt the ask prices slightly less (5.9% per auction) and they behave differently than the other categories (cf. confidence levels).

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[56] The value *f(x=0)* would represent the TDR price in the first auction, the value *f(x=1)* the price in the second auction etc.

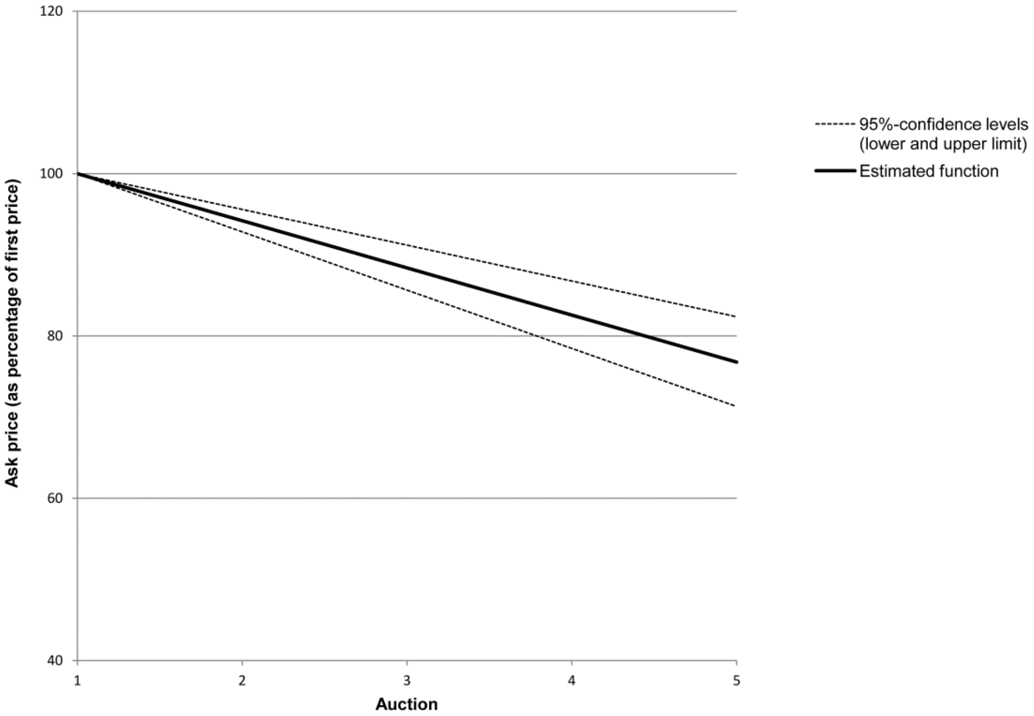

Fig. 3-2: Estimated function and confidence levels for senders of the category of enterprises.

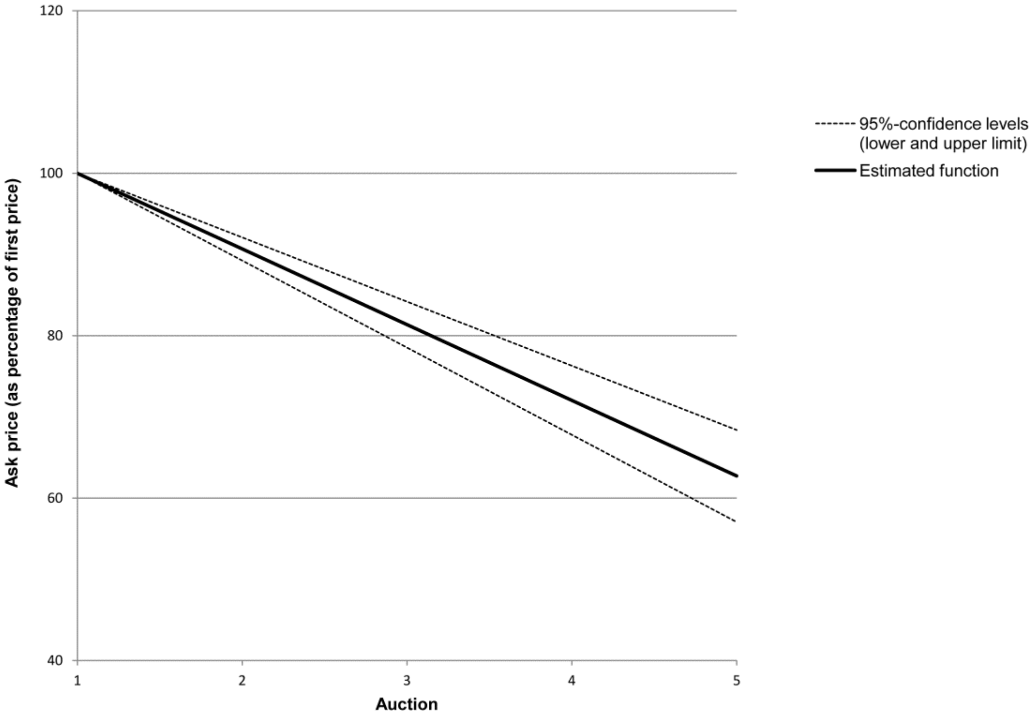

Fig. 3-3: Estimated function and confidence levels for senders of the category of NPI.

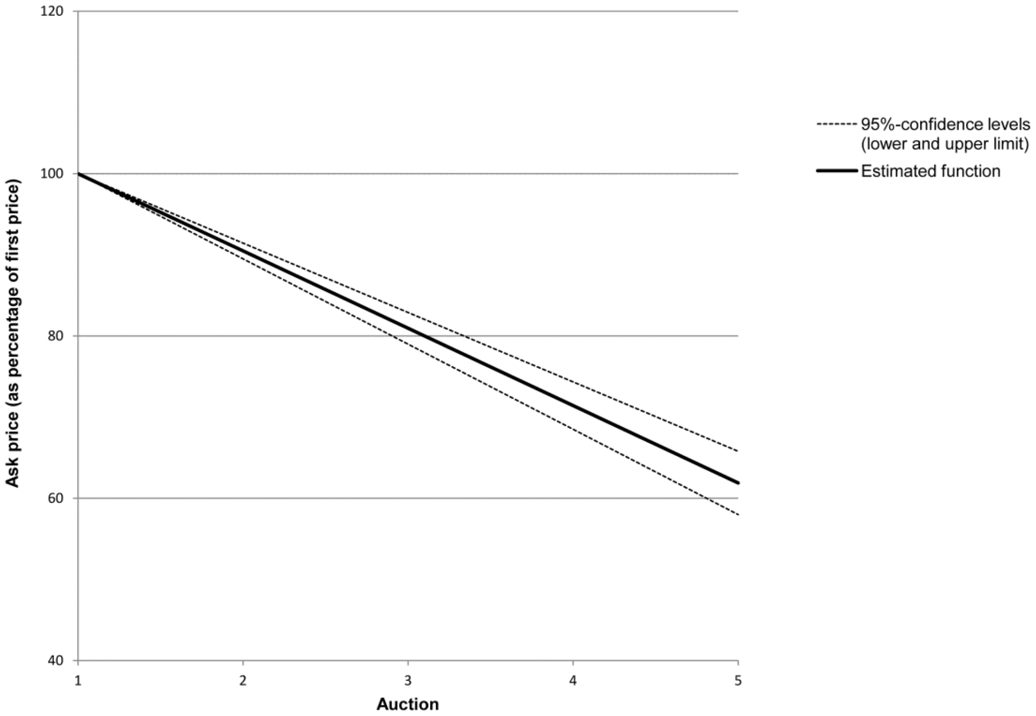

Fig. 3-4: Estimated function and confidence levels for senders of the category of RPP.

Receiver

The best results for the receivers were obtained with exponential functions (cf. Table 3-22 and eq. 3-5). The adaptation functions with the corresponding confidence levels are shown in the Fig. 3-5 to Fig. 3-7. The respondent-specific behavior can be found in the appendix B (cf. Fig. B-6 to Fig. B-8).

$$Bid(x) = 100 * exp(b1*x) \qquad (3\text{-}5)$$

with x=1 for the second bid price, 2 for the third, 3 for the fourth and 4 for the fifth.

Table 3-22: Adaptation functions for receivers of different categories.

	R^2	F	p-value	b1	Lower level of 95% confidence interval of b1	Upper level of 95% confidence interval of b1
Enterprises	0.572	76.546	0.000	0.103	0.091	0.115
NPI	0.786	194.863	0.000	0.148	0.136	0.160
RPP	0.345	75.414	0.000	0.124	0.106	0.143

The highest price adaptation – restricted to the interval of 5 auctions – can be observed in the NPI category, then in the RPP category followed by the enterprises category. Also here a statistically significant difference between enterprises and NPI could be found (cf. confidence intervals). However, there was no observable difference in the behavior between enterprises and RPP respectively NPI and RPP.

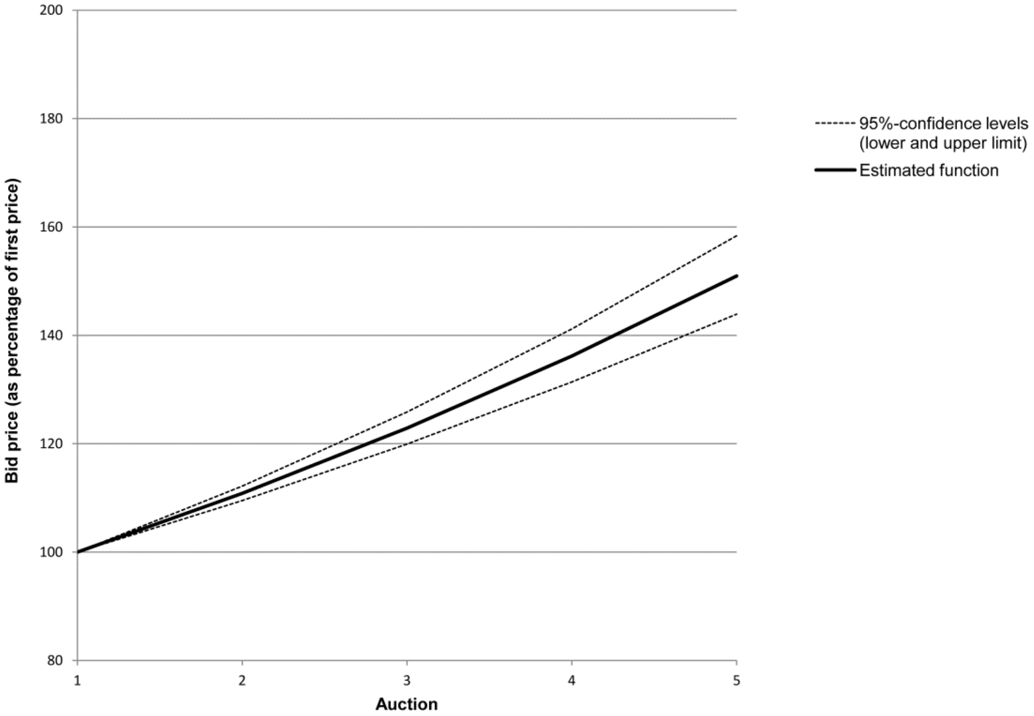

Fig. 3-5: Estimated function and confidence levels for receivers of the category of enterprises.

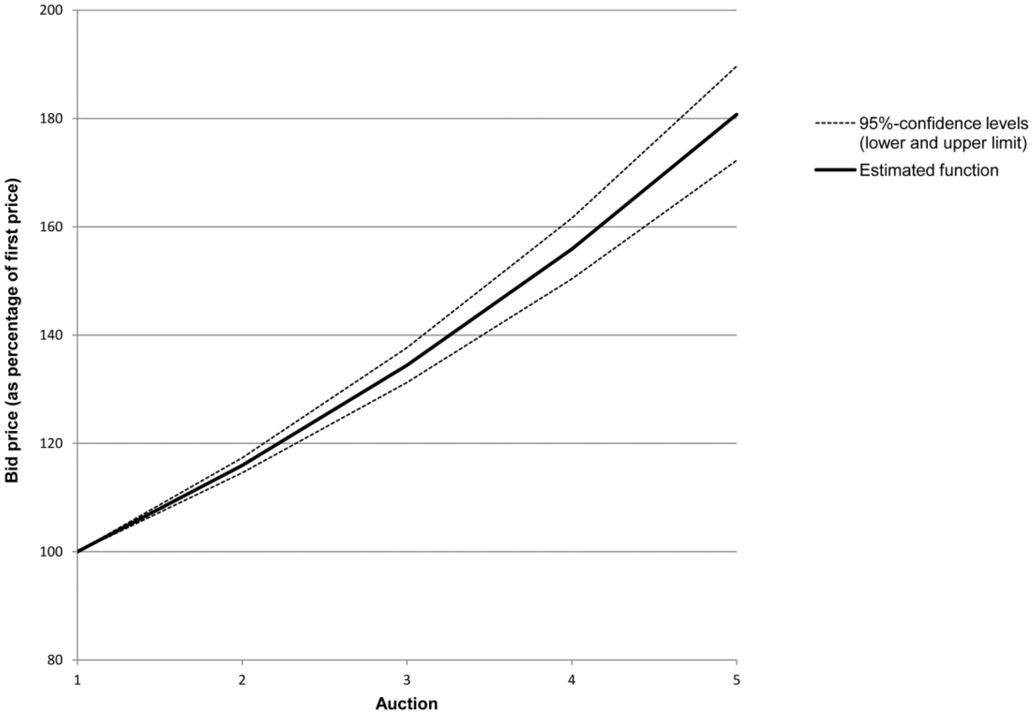

Fig. 3-6: Estimated function and confidence levels for receivers of the category of NPI.

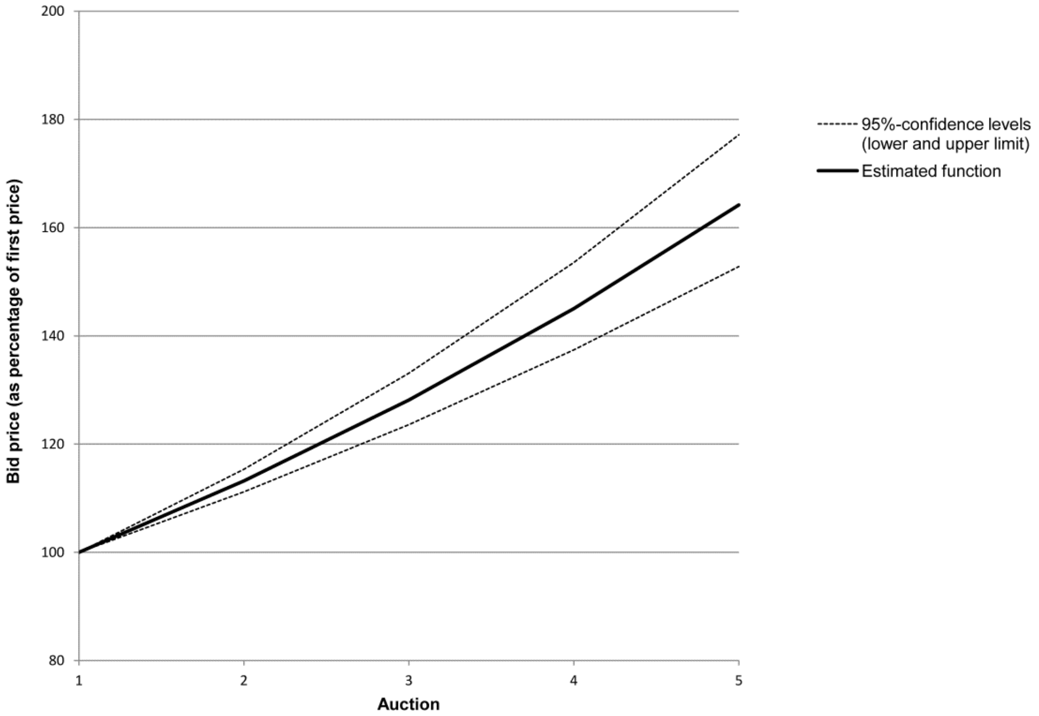

Fig. 3-7: Estimated function and confidence levels for receivers of the category of RPP.

The reported findings – and also the one for the senders – should be carefully interpreted: (1) the differences of the coefficients (b1) are low for the observed interval of 5 auctions, (2) the sample for the categories of enterprises and NPI are relatively small, and (3) in the questionnaire we asked the professionals to indicate the price for all five auctions under the assumption that they would have no success. We did not communicate the resulting market clearing price of each auction. This could not be implemented, because otherwise another kind of survey would have been needed which would have been more time-consuming and more complicated.

3.4 Discussion

In this paper we describe a questionnaire survey for collecting data to calibrate an agent-based model (TDR-ABM). The survey was specifically designed to calibrate the TDR-ABM and each single questionnaire stated a unique realistic situation that suited the contacted landowner category. This approach is special and turned out to be particularly advantageous, because of the implicit data variability that allowed the calculation of various linear models. Nevertheless, it is worth stating that the unique situation description and making the questionnaire available both in printed and online forms, was quite a time-consuming procedure.

Because of the complex topic and the previously lack of public information and debate about transferable development rights, we chose to contact professionals instead of a random sample of all existing and potential landowners. This decision proved to be well justified, because the respondents did not seem to have many problems filling out the questionnaire (stated difficulty in completing the questionnaire was rather low). However, the response rate was quite low. It might be that the low response rate could have been raised through special measures or incentives (e.g. prior recruitment through telephone survey, cf. e.g. Dillman et al., 2009, Axhausen and Weis, 2010). Such additional efforts could not be taken because of cost limitations and partly because of missing information e.g. telephone numbers.

As mentioned above, the questionnaire was distributed in a printed form with the additional possibility to fill it out online. Interestingly and unexpectedly only 21.4% used the online form. However, the ‘online-users’ were more willing to participate in the TDR market then the ‘paper-users’ (‘online-user’ participation probability of 62%, compared to 44% of the ‘paper-user’). For this reason, it can be concluded that the combination of a printed and online form turned out to be expedient.

The quite low willingness to participate in the TDR market should be put into perspective with the fact that there could have been considerable scepticism about a new instrument (e.g. because of a lack of information, strategic behavior etc.; cf. e.g. Gmünder, 2010). We claim that in a ‘real’ implementation of a TDR market the willingness to participate might be higher because of better information through the use of additional diffusion or communication instruments (e.g. reports in newspaper, oral presentations etc.), through self-diffusion effects (target people have an effect – voluntary or not – on the behavior of others) (cf. Kaufmann-Hayoz and Gutscher, 2001) and the fact that there would be no possibility to get a parcel of land developed without TDR, respectively not selling TDR would be like burning money.

In the questionnaire we ask the professionals to state the ask / bid price respectively for the TDR of a parcel with certain characteristics. Based on the stated prices we calculated different models that predict the TDR price as a function of the theoretical TDR price, the adaptation rate and the parcel area. We did not directly ask for the beta coefficients of our explanatory variables, because this would have led to a very complex questionnaire with many more questions. Furthermore, the stated coefficients of all respondents would have to have been averaged which would not have increased the model quality.

The adaptation of the TDR price during the five auctions has been estimated through fitting a polynomial function to the stated ask and bid prices. An alternative and probably better method would have been to analyze the data using time series analysis and to make appropriate models. However, as the collected data on price adaptations is not based on the resulting market clearing price of each auction, the simple adaptation functions seemed appropriate for the calibration of the TDR-ABM.

A significant disadvantage of a questionnaire survey is that usually there is no possibility to check back on potentially wrong responses due to misunderstandings of a complex topic. This might also have been the case in our study[57]. We excluded possible wrong responses with a plausibility test based on the theoretical TDR value (cf. section 3.3.1). This approach prevented model misspecifications, biased parameter estimations and incorrect results[58].

Another disadvantage or challenge in this study was the relatively small sample size we were able to gather, especially for the landowner categories of enterprises and NPI. Therefore, the interpretation of the coefficients and confidence intervals should be treated with caution. Our sample cannot be considered as representative for all existing and potential landowners and therefore, some conclusions are speculative as opposed to definitive.

A promising approach to address model uncertainties (e.g. not significant coefficients or values for the probability to participate in the TDR market) in the TDR-ABM is to vary the calibrated parameters within a certain interval of the calculated coefficients (sensitivity analysis). This is a major advantage of a simulation approach compared to a pure analytical method and can be implemented without too much additional effort.

3.5 Conclusions

The findings concerning our research questions can be summarized as follows:

(1) The landowner categories participated with different probabilities in the TDR market. Among the senders, the NPI were barely willing to sell TDR. The NPI were also largely unwilling to buy for any rights. The highest willingness to participate was found, for both senders and receivers, in the category of RPP.

(2) The most important criteria when determining the TDR price was the building zone price before introduction of TDR. Other important criteria were: the location quality, the need/desire to develop the parcel, the expected loss in value due to 'non-development' (sender) or the expected increase in value through the acquisition of TDR (receiver). There was no substantial difference between the different landowner categories.

(3) Two reasons were crucial for respondents who did not want to participate in a potential TDR market: the seemingly too complicated procedure of the TDR instrument and the high transaction costs. The landowner characteristics (e.g. experience in land sale or purchase) had no particular influence on the decision to participate in the TDR market or not.

(4) The TDR price (ask and bid) in the first auction was mostly determined by the theoretical TDR value (function of the building zone price, agricultural zone price and utilization factor;

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[57] A couple of respondents (5-10%) called to verify their answers.

[58] For more information on outlier detection methods see Ben-Gal (2005).

statistically significant in all models). Furthermore, the parcel area was significant in the model for senders in the enterprises category and the adaptation rate was significant in all receiver models. Additionally, for receivers in the RPP category the interaction between the adaptation rate and the parcel area was found to be significant.

(5) The three sender landowner categories did not behave significantly differently when determining the TDR price in the first auction. Among the receiver categories, NPI and RPP behaved with significant difference concerning the theoretical TDR value.

(6) The location factor seemed to have had no or just a very slight influence on the price that a landowner asked or paid for the TDR bundle of a parcel. The landowners seemingly had an idea of how much to ask (bid) for the parcel as a whole and consequently they changed their ask (bid) prices according to the number of TDR per parcel.

(7) The adaptation of the TDR price during the five auctions was partially dependent on the landowner category. Among the senders (linear adaptation functions), the ask price was most adapted by RPP, then by NPI and least by enterprises. A statistically significant difference could be found between enterprises and the other two categories. Among the receivers (exponential adaptation functions), the greatest price adaptation was observed in the NPI category, then in the RPP category, followed by the enterprises category. Here, only a statistically significant difference between enterprises and NPI could be found.

To conclude, the results show that the approach to collect data with a questionnaire survey to calibrate an agent-based model is useful. In particular, it revealed the usefulness of conducting a survey after determining the simulation model. This helps designing the questionnaire specifically to the needs of the model. Moreover, the comparison of the stated prices with theoretically expected prices allowed the detection and exclusion of potential outliers due to misunderstanding or lack of effort in answering the questions. This helped to prevent model misspecifications or biased parameter estimations.

When it comes to furthering this work (cf. chapter 4), the TDR-ABM was calibrated by incorporating the results of this study.

4 Results of the TDR market simulation*

Abstract: Transferable development rights (TDR) are discussed or applied in various countries for a wide variety of purposes, notably to increase building densities, to preserve natural areas, to compensate reduced development possibilities, and to control land use in rural areas. In Switzerland, TDR, a market-oriented planning instrument, might be used to reduce the land-use problems related to the unsustainable development of the settlement areas and to manage the problems with the spatially imbalanced supply and demand of existing undeveloped building zones.

The aim of this paper is to briefly introduce a TDR market concept for Switzerland, then to present an empirically calibrated agent-based TDR market simulation and finally analyze the detailed simulation results. We ran the simulation with five different settings which allowed the investigation of the impact of different agent behaviors and the impact of a change of land prices due to a new law restricting second home construction.

The results show that the TDR prices were comparable with existing land prices in Switzerland, i.e. prices to develop land would not rise. In addition, we are able to show that with the trade of TDR, it would be possible to downzone 11.4 km^2 of building zone land for which there is no demand and to develop 7.4 km^2 new building zone land up to the year 2018. Consequently, the defined building zone area would decrease, which would be in line with political objectives. Finally, we demonstrate that the popular initiative on second homes might only slightly reduce the building zone prices and thus had only a small effect on the TDR market price.

Keywords: Transferable Development Rights (TDR), TDR market, Agent Based Modeling (ABM), market simulation, market clearing price

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*This chapter is a slightly amended version of the paper “Results of an agent-based market simulation for transferable development rights (TDR) in Switzerland” written by Gianluca Menghini, Fabian Gemperle and Kay W. Axhausen. The paper has been submitted to the Journal *Environment and Planning B: Planning and Design* and is currently ‘under review’. The authors would like to thank the Swiss National Science Foundation for funding the project (K-21K1-1224), and Wüest und Partner AG, the cantons of Zurich, Thurgau and Fribourg for providing various data sets on building and agricultural land. Moreover, we thank PD Dr. Irmi Seidl from the Research Unit Economics and Social Sciences at Swiss Federal Institute WSL and Prof. Dr. Philippe Thalmann from the Research Group on the Economics and Management of the Environment at Ecole polytechnique fédérale de Lausanne (EPFL) for their valuable comments on an earlier version of this paper.

4.1 Introduction

Transferable development rights (TDR) – a market-oriented planning instrument – have been discussed since the late 1960s[59] and are applied or at least discussed in various countries. The instrument is widespread in the USA, and also partially applied in Australia, Canada, France, Germany, India, Italy, Japan, Latin America, the Netherlands, South Korea, Spain and New Zealand. The purposes range from increasing building density and the protection of monuments in cities to the preservation of natural areas, as well as for compensation for reduced development possibilities, and the control of land use in rural areas (Chomitz, 2004; Gibson, 1996; Henger and Bizer, 2010; Janssen-Jansen et al., 2008; Kaplowitz et al., 2008; Micelli, 2002; Pruetz, 2003; Tan and Beckmann, 2010).

In Switzerland, TDR might be applied as an instrument to reduce the land-use problems related to the unsustainable development of the settlement areas and to manage the problems caused by an imbalanced supply and demand of existing undeveloped building zones. In the last 30 years[60] the 23.5% increase of the settlement area has been related to population and economic growth, changes in lifestyle (e.g. greater demand of living space per person[61]) and to a formerly lax planning practice (see below). It has resulted in an increase of urban sprawl which has many negative consequences (for examples see e.g. Baumgartner 2005; Brownstone and Golob 2009 or Ewing 2008).

The problem with the spatially imbalanced supply and demand of undeveloped building zones is mainly caused by the permissive zoning practice of many municipalities and toleration of unlawful situations by authorizing public institutions (at canton and federal level). In the past, many municipalities – mainly in rural areas – have designated too large building zones with low densities. This practice was primarily intended to be an incentive for the influx of certain population groups and promised new tax revenues. However, this policy ignored the Swiss Federal Law on Spatial Planning[62] and led to an exceptionally strong imbalance of supply and demand for undeveloped building zones: In urbanized areas and along major transport routes the estimated demand in the next twenty years will considerably exceed the current reserves. In contrast, in rural areas the reserve of undeveloped building zones is significantly larger than the calculated demand for the next twenty years (ARE, 2008; Fahrländer Partner, 2008).

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[59] The idea of transferable development rights was first applied in New York City in the late 1960s for the protection of historic buildings (Johnston and Madison, 1997). It allowed landowners of protected sites to sell their unused development rights to adjacent parcels, which could then exceed their development potential.

[60] Results of the Areal Statistics 1979/85 – 2004/09 (http://www.bfs.admin.ch/bfs/portal/de/index/themen/02/03.html, accessed: 2012-11-02)

[61] The amount of living space per person increased from 34m^2 in 1980 to around 50m^2 at present. This trend continues and it is estimated that in 2030 this space will be 55m^2 (http://www.are.admin.ch/dokumentation/01378/04315/index.html?lang=de, accessed: 07-28-2012).

[62] According to the Swiss Federal Act of 22 June 1979 on Spatial Planning, the designated building zones should not be greater than the anticipated demand for the next 15 years.

In order to solve this imbalance and to reduce the high land consumption, the Swiss population accepted the revision of the Swiss Federal Spatial Planning law. The revision includes, among others, measures for the mobilization of hoarded zones of building land on suitable areas according to Swiss spatial planning principles and, more importantly, downzoning[63] building zones for which there will be no demand in the next 15 years.

In Switzerland, in most cases the landowners whose parcel is downzoned will have to be fully compensated because changing its status from the building zone to the agricultural zone is a form of material expropriation of the owner. Many municipalities and cantons cannot finance this[64]. For example, in the canton of Valais, the building zone reserves are three to four times larger than allowed by the Swiss Federal Spatial Planning law. Another example is the Canton of Vaud, where the reserves in two third of the municipalities are twice as large as permitted (cf. calculations of Fahrländer Partner, 2008). Again, it is doubtful whether these municipalities have the financial means to put the proposed downzoning into practice.

A solution to reduce these problems are transferable development rights (TDR). They allow transferring development rights, and the result of such transfers may be seen as a form of rezoning. In a TDR market, landowners in 'sending areas' can sell their right to build to landowners in 'receiving areas'. This results in less land consumption in the former and increased density in the latter, since in the receiving area there might be denser development (higher utilization factor, cf. section 4.2.2) compared to the density in the sending area.

In the first paper (chapter 2) both a concept for a Swiss TDR market and an agent-based model for simulating the proposed market (called TDR-ABM) is presented. The concept was discussed in a workshop[65] with spatial planning and real estate experts, and therefore it includes ideas and suggestions of landowners involved in such a potential market. The agent-based simulation was developed to assess the demand, supply and prices in such a market and because there may not be any political willingness to implement such an instrument without prior information on its likely effects.

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[63] The practice of reducing the zoning of land from building to agricultural zone.

[64] BSS (2011) estimate for the whole of Switzerland that with a zoning tax of 25% (tax on planning gains, skimming of planning surplus values), in the next 20 years, only 36% (10,000 hectares) of the unwanted existing building zones could be downzoned. However, there are considerable regional differences. The lowest financial potential to compensate downzoning of not demanded building zones exists in the cantons of Valais, Glarus, Ticino, Basle-Land and Jura. Furthermore, following the legislation proposals the zoning tax would have to be paid only in the case the planning gain is realized, that is the parcel would be developed or sold. This causes a problematic temporal delay in comparison to the immediate compensation of landowners whose parcel would be downzoned.

[65] Participants were experts from local authorities (Confederation/Canton/Municipality), banks, real estate companies, a planning association and academics.

An agent-based model was chosen – instead e.g. of a pure analytical method – because of the heterogeneous participants[66] in the TDR market. With an agent-based model it is possible to model individual decision-making and human behavior (e.g. the degree of rationality, risk aversion, learning abilities etc.) which is essential for simulating the TDR market. Furthermore, it is possible to consider special variables/parameter distribution patterns or to reduce random effects (e.g. probability to participate in the TDR market) by running the simulation many times (e.g. 100 times) and then averaging the results from all runs. However, up to this point, the simulation (for the model prototype cf. chapter 2, section 2.3) has not yet been calibrated with empirical data and therefore lacks empirical validation.

Agent-based models have been successfully applied in several land-use related applications such as policy analysis and planning (e.g. Happe et al., 2006), participatory modeling (e.g. D'Aquino et al., 2003), explaining spatial patterns of land use or settlement (e.g. Parker and Meretsky, 2004), testing social and economic science concepts (e.g. Polhill et al., 2001), or for modeling land use functions (e.g. An et al., 2005). For more information about agent-based models related to land-use see e.g. Filatova et al. (2009), Magliocca et al. (2011) or Matthews et al. (2007).

The aim of this paper is to present the empirically calibrated simulation model of the potential Swiss TDR market and the associated results. The results will show the impact of a potential implementation of a TDR market and will therefore inform the public and expert debate. Moreover, the impacts of a change of land prices due to new law will be analyzed, i.e, the impact of the adoption of the 'popular initiative[67] on second homes' in Switzerland (adopted on 11 March 2012). Since 22 August 2012 an ordinance for second homes applies to municipalities with more than 20% of second homes. In those municipalities building further second homes[68] is no longer allowed. This restriction might have a negative effect on the price of building land (cf. Kaufmann and Rieder, 2012; NZZ, 2012) and therefore on the TDR price. Such a situation will be analyzed in one of the model settings (cf. section 4.4).

In the next section we will present in detail the TDR market concept, the data preparation and the calculations for the study area. The research questions will be presented in section 4.2.3. Afterwards (section 4.3), the TDR-ABM and in particular the involved agents are described. This is followed by a presentation of the results of the various model settings (section 4.4), a discussion of the main findings (section 4.5) and conclusions (section 4.6).

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[66] Here, the market participants (agents) represent landowners of different categories such as enterprises (banks etc.), individual persons, social organizations (e.g. cooperatives etc.) or the state.

[67] This is an instrument of direct democracy, by which, at federal level a minimum of 100,000 voters request to adopt, repeal or amend a provision of the constitution.

[68] For more information see: http://www.are.admin.ch/themen/raumplanung/00236/04094, accessed: 09-18-2012.

4.2 Applying TDR in Switzerland

4.2.1 TDR market concept

In the following we present the central features of the proposed TDR market. (A comprehensive description of the proposed TDR market is presented in chapter 2).

The design of the TDR market focuses on the imbalanced supply and demand of the existing building zones in Switzerland and proposes to reduce this problem by trading development rights (TDR), which can be transferred from sending to receiving areas. A precondition of this dual-zone program is setting an overall cap for new building zones (following the cap-and-trade principle).

In Switzerland, the designation of appropriate sending and receiving areas would ideally be done by the cantons and then in detail by the municipalities. The sending areas are composed of undeveloped building zone parcels for which there is no demand and/or which should be downzoned according to Swiss law because there is no need for them over the next 15 years. The receiving areas consist of parcels not yet designated as building zones, which – according to Swiss law – should be developed in the future because of high demand.

After the designation of the sending and receiving areas, the TDR initially need to be allocated. Here, a free allocation to the landowners in the sending area (called ‘senders’ or ‘sender agents’) is proposed (known as grandfathering principle). Those landowners can then decide to sell their awarded TDR to the landowners in the receiving area (called ‘receivers’ or ‘receiver agents’). In the case of a successful sale, the corresponding parcel in the sending area will be downzoned to agricultural land. The receivers need to buy a certain number of TDR to be allowed to develop their parcel.

The number of TDR per parcel depends – for both senders and receivers – on the parcels’ size and the allowed utilization factor (cf. section 4.2.2). Moreover, the TDR per parcel have to be sold or bought as a whole (called ‘TDR bundle’). This is an incentive for the receivers to develop the maximum allowable gross floor area[69] per parcel (high density development), and the senders are fully compensated for the loss of their development possibility in a single transaction. As a result the number of transactions and consequently transaction costs[70] will be reduced.

The TDR are traded on a ‘TDR platform’ (called ‘trading agent’) following the rules of a multi-unit double auction (MDA) with a uniform price: Each landowner of the sending or receiving area can submit (voluntary participation) an ask (sender) with the desired price per TDR, respectively a bid (receiver) with the price s/he is willing to pay for the TDR needed. Then, at the end of the trading period (representing one year), the trading agent sorts the asks by price in ascending, the bids in descend-

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[69] Also known as ‘living area’.

[70] Costs associated with the exchange of goods or services, including information, negotiation, communication control costs.

ing order and calculates the market clearing price. The market price is at the intersection of the ask- and bid-curves.

All sender agents who asked a price below or equal the market clearing price and all receiver agents who bid a price above or equal the market clearing price are successful. The other participating agents are unsuccessful and have the chance to participate in the next auction and to adapt their ask or bid prices respectively.

It is suggested that there should be two rounds of five auctions[71], with one year between each auction. The time for five auctions (=5 years) allows the municipalities to adapt their zoning plans, i.e. designate sending and receiving areas, for the next round. The auctions are only conducted once a year in order to encourage the market participants to bid more truthfully, as it takes a long time until the next trading opportunity.

4.2.2 Study area – data preparation and calculations

Switzerland covers an area of 41,284.9 km^2 of which 6.8% is settlement area (SFSO, 2010a). The greater part (around 82%) of the settlement area consists of building zones, whose area is 2,270 km^2 [72]. Of this area, between 378 and 528 km^2 (17 to 24%)[73] have not been developed. According to ARE (2008) and Fahrländer Partner (2008) these undeveloped building zones could provide space for about two million additional inhabitants. Switzerland has a present population of approximately 8 million inhabitants and current predictions (medium scenario) are that a peak will be reached in 2055 at 9 million inhabitants (SFSO, 2010c).

Designation of sending and receiving areas

Following existing analyses of supply (cf. ARE, 2008) and demand (cf. Fahrländer Partner, 2008) for building zones, we calculated for each Swiss municipality the quantity of TDR of the potential sending and receiving areas for the year 2018[74]. The following assumptions were made: (1) In order to have a homogenous market, only residential zones were considered. (2) The demand for building zones by Fahrländer Partner (2008) was reduced by considering the development potential not used so far[75] (the additional gross floor area that can be realized without TDR). According to a study of the Canton of

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[71] In the TDR-ABM we simulate only one round with 5 auctions.

[72] The residential zone area is 1,054 km^2, of which 183 to 277 km^2 have not been developed.

[73] Because of the fact that this calculation have been made in 2008, we assume for our study that 378 km^2 (17%) of the existing building zone area is undeveloped.

[74] We are interested to model the possible impacts of five auctions from 2013 – 2018 (end of 2017). For that purpose we calculate the potential sending and receiving area that would be available for the year 2018.

[75] In Switzerland, landowners typically do not realize the development density permitted by law. For example, in the Canton of Zurich, it is only 66% of the currently permitted gross floor area (Kanton Zürich, 2009). Thus, there is potential to build much more densely, and increasing density to the legal limit would not require TDR programs.

Zurich, between 1993-2005, 54% of the newly built floor area was realized in already developed building zones by using the available development potential (inner densification, Germ: “Innere Verdichtung”) (Kanton Zürich, 2007). As the overall pressure for using this potential is rather lower outside Zurich, for the whole of Switzerland it was assumed that at maximum 40% of the demand could be realized by using the inner development potential[76]. (3) Since the supply and demand datasets are based on different years[77], we scaled them linearly[78] so that both datasets represent the same year of origin. (4) The total sending area (considering all municipalities) has been capped in a way[79] that the total TDR quantity in both the sending and receiving area is nearly the same. This was done in order to designate a total sending area that is only as large as necessary. However, it was not possible to calculate the identical TDR quantity in both areas because the parcel sizes had to represent realistic distributions regarding the landowner categories and municipality types (cf. sub-section below: *Designation of land parcels*).

Based on the above assumptions and calculations, a municipality was assigned to the sending area if its existing undeveloped building zone area exceeds the projected demand until 2018. On the other hand, a municipality was assigned to the receiving area if the projected demand exceeds the supply of undeveloped building land until 2018.

Designation of land parcels

After having calculated the size of the sending and receiving areas per municipality, those areas were divided into realistic parcel sizes. This division was based on empirical data of parcel sizes, which were derived from a database of more than 91,000 transactions of building zone parcels over the last 20 years (Wüest und Partner AG 2011), and digital cadastral data from the Cantons of Zurich and Thurgau.

Calculation of utilization factor and assignment of landowner categories

The transaction database and the digital cadastral data were also used to calculate the legal utilization factor *UF* per parcel. This factor determines – together with the parcel area – the legally allowed floor area and thus the quantity of TDR per parcel (cf. eq. 4-1).

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[76] The Institute for spatial development at ETH Zurich (IRL) is about to develop a detailed method to identify inner development potentials in settled areas (e.g. unbuilt sections between settled areas). As, so far, the investigation only covers a few cantons, we did not use the partial results but made a rough estimation. For more information see: http://www.raumplus.ethz.ch, accessed: 10-18-2012.

[77] The study by Fahrländer Partner (2008) calculated demand values for the periods 2005 up to 2010, 2015, 2020, 2025 and 2030. In contrast, the data about the supply of undeveloped building zone areas is from the year 2007 (ARE, 2008).

[78] We assumed a linear increase resp. decrease of the aggregated demand resp. supply values over time.

[79] In proportion to the area of undeveloped building zone parcels per municipality.

Finally, we assigned to the individual parcels different landowner categories using proportions found in land registry data of various municipalities in the Canton of Grisons, as well as transaction data of undeveloped land parcels (building and agricultural zones) of the Cantons of Zurich and Fribourg. The following landowner categories are distinguished:

- Enterprises[80] operating in the commercial real estate market *('enterprises')*
- Confederation/Cantons/Municipalities/Social Organizations[81] *('non-profit institutions', 'NPI')*
- Individuals/married couples/simple partnerships[82] *('individuals')*

The characteristics of the sending and receiving areas for the year 2018 are summarized in Table 4-1. A more detailed description (characteristics per municipality type and canton) can be found in the appendix C (cf. Table C-1, Table C-2 and Fig. C-1)

Table 4-1: Characteristics of the sending and receiving areas for the year 2018 (own calculations, data basis: ARE, 2008 and Fahrländer Partner, 2008).

	Number of landowners (parcels)	**Area (in km2)**	**Assigned TDR quantity**
Sending area	30,195	31.88	9,174,943
Receiving area	19,264	20.49	9,034,348

4.2.3 Detailed research questions

We formulated the following research questions: (1) What TDR market prices arise and what would be the overall financial volume traded? (2) How do TDR market prices evolve over the five auctions? (3) How many TDR are traded and how much land could be downzoned in the sending area and developed in the receiving area? (4) How much land could be downzoned in the canton of Valais? (5) How do TDR market prices and traded volumes change if we assume that all agents behave rationally? (6) Do the TDR market prices change when the participation rates increase/decrease by 10% or 20%? (7) What impact might the 'popular initiative on second homes' have on the TDR market?

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[80] Corporation, Limited Liability Partnership, Bank, Insurance Company etc.

[81] Cooperatives, associations etc.

[82] In the TDR survey (cf. chapter 3) it was supposed that architects and real estate developers should represent the interests of individuals, married couples and simple partnerships.

4.3 TDR market simulation model (TDR-ABM)

In the following section the basics of the TDR-ABM are explained. A more detailed description can be found in chapter 2 (first paper, section 2.3). The calibration of the model with survey data is described in section 4.3.3.

4.3.1 Agents' description

The simulation model TDR-ABM[83] distinguishes three main types of agents: two types representing landowners in the sending and receiving area (called sender agents or sender, receiver agents or receiver) and one type representing the market platform (trading agent). Each agent is characterized by different attributes (state variables, e.g. parcel area) and behavior (e.g. price adaption coefficients) derived from existing data and from a dedicated questionnaire survey. The questionnaire survey data is used to define realistic behavior of the market participants (e. g. participation probability p_{send} and $p_{receive}$ per landowner category). An overview of the most important variables of the sender and receiver agents is provided in Table 4-2[84]. The data basis used is illustrated in Fig. 4-1, the central variables of the trading agent are listed in section 4.3.4.

Moreover, Fig. 4-2[85] illustrates all agent's states and transitions, actions and communication for iteration *t*.

Table 4-2: State variables of sender and receiver agents (differing variables of sender and receiver agents are highlighted in grey).

Sender agents	**Receiver agents**	**Data source**[a]
Parcel-ID: $\boldsymbol{ID} \in \mathbb{N}$	Parcel-ID: $\boldsymbol{ID} \in \mathbb{N}$	Own calculation
Landowner category: $\boldsymbol{LC} \in$ {„Enterprises", "NPI", "Individuals"}	Landowner category: $\boldsymbol{LC} \in$ {„Enterprises", "NPI", "Individuals"}	Own calculation based on (B)
Parcel area (in sqm): $\boldsymbol{A} \in \mathbb{R}^+$	Parcel area (in sqm): $\boldsymbol{A} \in \mathbb{R}^+$	Own calculation based on (A), (B)
Utilization factor: $\boldsymbol{UF} \in \mathbb{R}^+$	Utilization factor: $\boldsymbol{UF} \in \mathbb{R}^+$	Own calculation based on (A), (B)
Building zone price in CHF per square meter (in municipality): $\boldsymbol{BLP} \in \mathbb{R}^+$	Building zone price in CHF per square meter (in municipality): $\boldsymbol{BLP} \in \mathbb{R}^+$	Own calculation based on (A)

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[83] The simulation has been programmed in Java with use of the free and open source agent-based modeling and simulation platform Repast Simphony (http://repast.sourceforge.net, accessed: 2012-09-15).

[84] Note that Table 4-2 is slightly different from Table 2-1.

[85] Note that Fig. 4-2 is slightly different from Fig. 2-6.

Agricultural land price in CHF per square meter (in municipality): $\boldsymbol{ALP} \in \mathbb{R}^+$	Agricultural land price in CHF per square meter (in municipality): $\boldsymbol{ALP} \in \mathbb{R}^+$	Own calculation based on (B)
Current sender agent state: $\boldsymbol{s_s} \in$ {„notyetsending“, „sending“, „sent“}	Current receiver agent state: $\boldsymbol{s_r} \in$ {„notyetreceiving“,„receiving“, received“}	Own calculation
Quantity of TDR to sell: $\boldsymbol{q_s} \in \mathbb{N}_0$	Quantity of TDR to buy: $\boldsymbol{q_r} \in \mathbb{N}_0$	Own calculation based on (A), (B)
Probability to enter into the sending and trading process: $\boldsymbol{p_{send}} \in [0,1] \subset \mathbb{R}_0^+$	Probability to enter into the receiving and trading process: $\boldsymbol{p_{receive}} \in [0,1] \subset \mathbb{R}_0^+$	Own calculation based on (C)
Current ask price in CHF per TDR (CHF per saleable square meter of building area that potentially can be developed): $\boldsymbol{p_{ask}} \in \mathbb{R}^+$	Current bid price in CHF per TDR (CHF per purchasable square meter of building area that potentially can be developed): $\boldsymbol{p_{bid}} \in \mathbb{R}^+$	Own calculation based on (C)
Ask price initialization coefficients: $\boldsymbol{\beta ask_i} \in \mathbb{R}^+$, where $i \in$ {“ParcelArea”, “PTDRtheoretical”}	Bid price initialization coefficients: $\boldsymbol{\beta bid_i} \in \mathbb{R}^+$, where $i \in$ {“ParcelArea”, “PTDRtheoretical”}	Own calculation based on (C)
Ask price initialization constant: $\boldsymbol{C_{ask}} \in \mathbb{R}^+$	Bid price initialization constant: $\boldsymbol{C_{bid}} \in \mathbb{R}^+$	Own calculation based on (C)
Ask price adaptation coefficient: $\boldsymbol{a_{ask}} \in \mathbb{R}^+$	Bid price adaptation coefficient: $\boldsymbol{a_{bid}} \in \mathbb{R}^+$	Own calculation based on (C)
Surplus of realized trade in CHF: **sur** $\in \mathbb{R}^+$	Surplus of realized trade in CHF: **sur** $\in \mathbb{R}^+$	Own calculation

[a] Data sources: (A) Database of building zone parcels (based on 91,000 transactions over the last 20 years) (Wüest und Partner AG 2011), and digital cadastral data from the Cantons of Zurich and Thurgau. (B) Land registry data of various municipalities in the Canton of Grisons, as well as transaction data of undeveloped land parcels (building and agricultural zones) of the Cantons of Zurich and Fribourg. (C) Results of a questionnaire survey among potential landowners (cf. chapter 3).

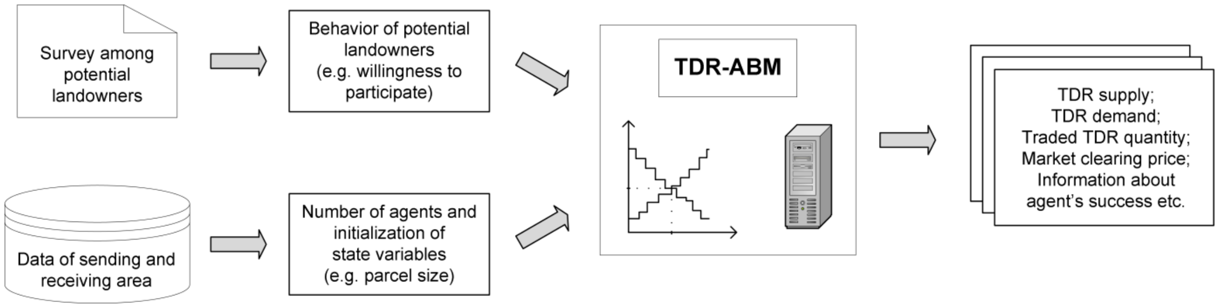

Fig. 4-1: Overview of the data basis of the TDR-ABM.

4.3.2 The calibration of the agents’ behavior

In order to simulate behavior of potential market participants realistically, the sender and receiver agents have been calibrated with results of a survey (‘TDR survey’) among professional representatives of the above mentioned landowner categories. In the survey, the respondents had – among others – to state their willingness to participate in a TDR market and their price expectations (TDR ask and bid prices during five auctions). Based on this, it was possible to calculate agent-specific participation probabilities (cf. Table 4-3), functions for the TDR price setting (asks and bids; cf. eq. 4-2 and 4-3, Table 4-4 and Table 4-5) and functions for the TDR price adaptation (cf. eq. 4-7 and 4-8, Table 4-6). Regressions models with different explanatory variables (e.g. theoretical TDR price, landowner category etc., cf. chapter 3, section 3.3.3) were calculated.

4.3.3 Sender and receiver agents: The supply and demand side of the TDR market

As described in section 4.2.1, both sender and receiver agents decide first whether they want to participate in the TDR market or not (cf. Fig. 4-2)[86]. The assigned probability rates for each agent and landowner category are presented in Table 4-3 (cf. chapter 3).

Table 4-3: Sender and receiver participation probability per landowner category.

Variable name	Enterprises	NPI	Individuals
p_{send}	51.4%	34.8%	62.5%
$p_{receive}$	53.8%	21.9%	66.7%

In the case of an agent deciding to participate, s/he submits a first ask (sender) or bid price (receiver) for the number of TDR s/he disposes of (sender) or needs (receiver) for her/his parcel. The quantity of TDR per parcel (q_s, q_r) is calculated as follows:

$$q = A * UF \qquad (4\text{-}1)$$

where A represents the parcel area in square meter and UF the utilization factor.

The general form of the functions[87] for the initialization of the TDR price are given in equations 4-2 (sender) and 4-3 (receiver). The corresponding coefficients are listed in Table 4-4 and Table 4-5.

$$p_{ask} = C_{ask} + \beta ask_A * A + \beta ask_{PTDRtheoretical} * PTDRtheoretical \qquad (4\text{-}2)$$

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[86] Note that the decision to participate in the TDR market or not can only be made in the first auction.

[87] Note that the explanatory variable '*AdaptationRate*' (cf. chapter 3, section 3.3.3) could not be considered here because the input data (cf. table B.1 in the appendix) of the TDR-ABM do not allow a calculation of agent-specific values of this variable. It would only be possible to calculate an average value per agent type and landowner category, which however, would not increase the model quality because it would be no more than an additional constant. For this reason, the regression functions in chapter 3 (section 3.3.3) have been recalculated without the variable '*AdaptationRate*'. In the rare case the dependent variables (p_{ask}, p_{bid}) become negative, the theoretical TDR value is used instead.

$$p_{bid} = C_{bid} + \beta bid_A * A + \beta bid_{PTDRtheoretical} * PTDRtheoretical \quad (4\text{-}3)$$

where C_{ask} (C_{bid}) is the landowner specific ask (bid) price initialization constant, βask_A (βbid_A) the landowner specific ask (bid) price initialization coefficient for the parcel area (A), $\beta ask_{PTDRtheoretical}$ ($\beta bid_{PTDRtheoretical}$) the landowner specific ask (bid) price initialization coefficient for the theoretical TDR value (*PTDRtheoretical*). The theoretical TDR value is calculated as follows:

$$PTDRtheoretical = (BLP - ALP)/UF \quad (4\text{-}4)$$

All variables are defined in Table 4-2. The theoretical TDR value can be explained as follows: When the price of agricultural land is 6 CHF/sqm for instance, the price of building zone land 500 CHF/sqm and UF = 0.3, then 0.3 TDR are needed to transform land worth 6 CHF into land worth 500 CHF, so the TDR might be worth 494/0.3 = 1,650 CHF/TDR (=*PTDRtheoretical*) (cf. chapter 3). To extend this example, let us further assume that a sender agent of the landowner category ‘enterprise’ owns a parcel of 1000 sqm with the above mentioned properties and coefficients of Table 4-4. In that case, the ask price would be: 1263.685 - 0.978*1000 +1.063*1,650 = 2,040.64 CHF/TDR. This price is above the theoretical value – which is expected – because the sender agents might think strategically and try to enhance their surplus[88] in the first auction.

Table 4-4: Coefficients of the three landowner categories for initialization of the ask price.

Variable name	**Enterprises**	**NPI**	**Individuals**
C_{ask}	1263.685	735.616	243.811
βask_A	-0.978	-0.613	-0.013
$\beta ask_{PTDRtheoretical}$	1.063	1.139	0.925

Table 4-5: Coefficients of the three landowner categories for initialization of the bid price.

Variable name	**Enterprises**	**NPI**	**Individuals**
C_{bid}	242.961	439.372	88.068
βbid_A	-0.008	-0.237	-0.148
$\beta bid_{PTDRtheoretical}$	0.398	0.303	0.667

After the submission of all asks and bids in the first auction (first iteration), the trading agent calculates the market clearing price (cf. section 4.3.4), and informs the agents about their success. The suc-

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[88] The difference between the market clearing price and the actual bid (willingness to pay) respectively ask price (willingness to accept).

cessful agents ‘finalize’ (cf. Fig. 4-2), change their state to ‘sent’ respectively ‘received’ and calculate their surplus (eq. 4-5 for senders, eq. 4-6 for receivers, cf. also Fig. 2-7):

$$sur = (p_{clear} - p_{ask}) * q_s + \varepsilon_s \quad (4\text{-}5)$$

$$sur = (p_{bid} - p_{clear}) * q_r + \varepsilon_r \quad (4\text{-}6)$$

where p_{clear} represents the market clearing price (cf. section 4.3.4), p_{ask} (p_{bid}) the current ask (bid) price, q_s (q_r) the sold (bought) TDR quantity and ε_s (ε_r) the error term of the respective calculation.

In the case of failure (too high ask price or too low bid price), the sender agents decrease their ask price and the receiver agents increase their bid price (‘adapt’ in Fig. 4-2).

Based on data fitting in chapter 3 (section 3.3.3) the sender agents adapt their ask prices linearly (cf. eq. 4-7 and Table 4-6) and the receiver agents exponentially (cf. eq. 4-8 and Table 4-6):

$$p_{ask}(x) = (p_{ask} - a_{ask} * x) *1.009 \quad (4\text{-}7)$$

$$p_{bid}(x) = p_{bid} * exp(a_{bid} * x) *1.009 \quad (4\text{-}8)$$

where x represents the auction number, p_{ask} (p_{bid}) the ask (bid) price in the first auction and a_{ask} (a_{bid}) the landowner specific ask (bid) price adaptation coefficient.

Table 4-6: Adaptation coefficients of the sender and receiver agents.

Variable name	**Enterprises**	**NPI**	**Individuals**
a_{ask}	5.909	9.367	9.780
a_{bid}	0.103	0.148	0.124

In order to take into account increasing land prices over time, we implement the Consumer Price Index (*CIP*) in the adaptation functions. This factor represents the change in prices of goods and services which are representative of the private household consumption in Switzerland. For our simulation we calculated the factor by using the average value of the last 20 years (1993-2012)[89], 0.9% per year.

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[89] We have chosen the *CIP* (cf. http://www.bfs.admin.ch/bfs/portal/en/index/themen/05/02/blank/key/basis_aktuell.html , accessed: 2012-09-02) and not a land price index as calculated in Bourbassa et al. (2010). The reason is that the land price index has a high volatility and depending on the time period considered the results could be significantly different. Moreover, in the long term the increase of land prices (land price index) seems to be closely related to the *CIP* development.

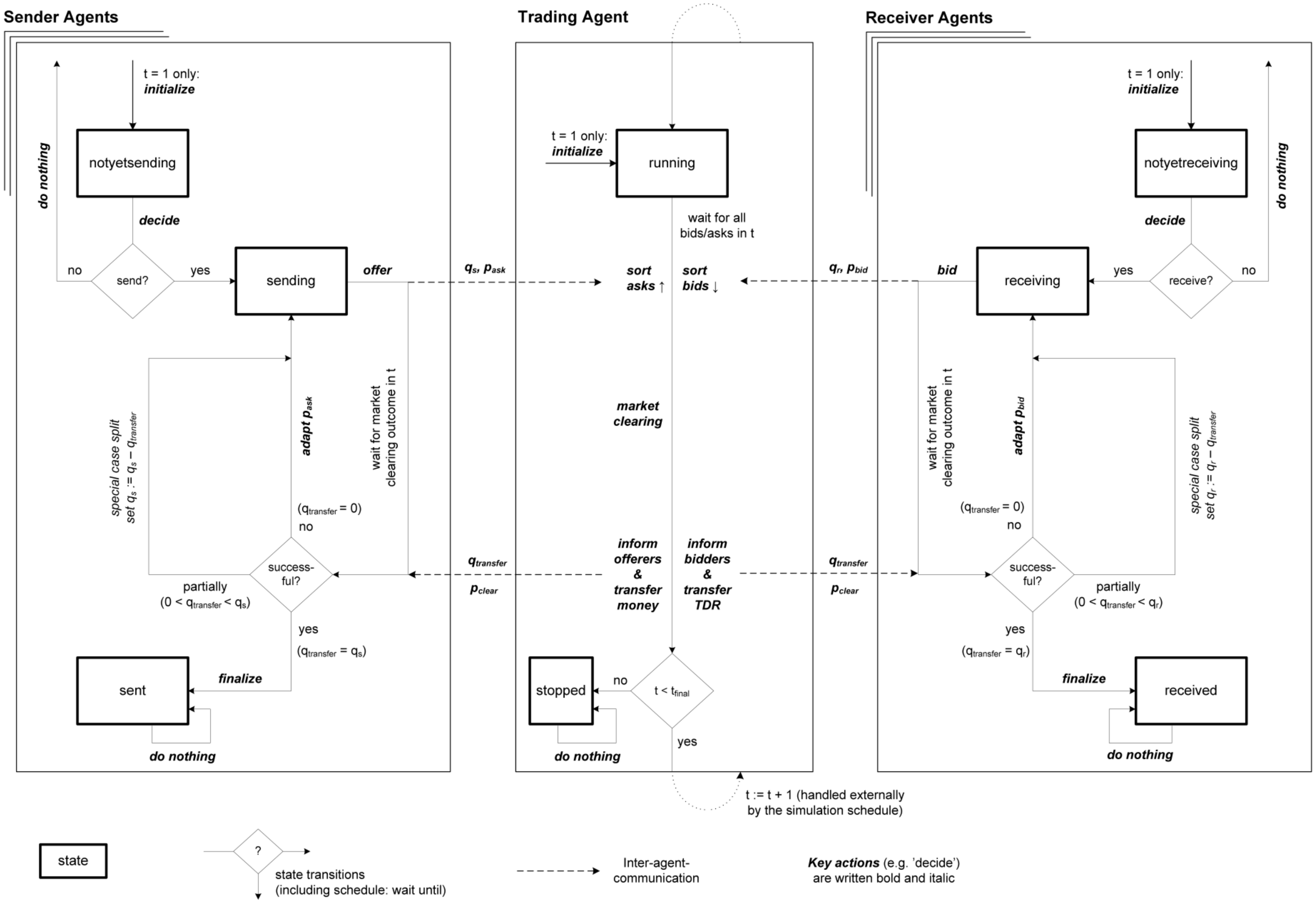

Fig. 4-2: Agents' states and transitions, actions and communication for some iteration *t*.

4.3.4 Trading agent: the operator of the TDR market platform

The trading agent organizes the communication between the sender and receiving agents and calculates the market clearing price for each auction. It (trading agent) is characterized by various auxiliary variables for intermediate calculation steps and by four variables of particular importance since they represent the macroeconomic outcome of each trading cycle:

- Market clearing price in CHF/TDR: $\boldsymbol{p_{clear}} \in \mathbb{R}^+$
- Total quantity of TDR supply: $\boldsymbol{q_{supply}} \in \mathbb{N}_0$
- Total quantity of TDR demand: $\boldsymbol{q_{demand}} \in \mathbb{N}_0$
- Total quantity of TDR sold (traded): $\boldsymbol{q_{trade}} \in \mathbb{N}_0$

In each auction the trading agent sorts the asks in ascending price, the bids in descending price order and calculates the market clearing price p_{clear} in accordance with the principle of an MDA. The price is at the intersection of the cumulated ask and bid price curves (cf. Fig. 2-7). Since the traded TDR bundles have different sizes, in most cases, the TDR bundle of the last successful agent[90] has to be split (for more information about all split cases, cf. Fig. A-2 in appendix A). The affected agent participates automatically in the subsequent auction with the leftover TDR of the TDR bundle and with an adapted ask or bid price. In the case it is the last auction, then the leftover TDR are bought or sold by the operator of the TDR market platform (e.g. government).

After each trading period, the trading agent informs the sender and receiver agents about their trading result (p_{clear} and $q_{transfer}$, cf. Fig. 4-2). The successful receiver agents all have to pay the same (uniform) market clearing price.

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[90] In the case that more than one TDR bundle could be split (multiple agents with the same price), the order of the TDR bundles is determined by the submission time (here: randomly chosen) of the bids and asks.

4.4 Results

In the following section, we present five different model settings matching our formulated research questions (cf. section 4.2.3), with the particular aim of calculating the resulting prices and traded quantities of TDR.

Note that with 'rational behavior' we mean that the ask and bid prices are calculated in accordance with the theoretical TDR value (cf. eq. 4-4).

- ***Model setting 1*****:** Participation probability and behavior of sender and receiver agents according to the TDR survey;
- ***Model setting 2*****:** Participation probability according to the TDR survey and rational behavior of sender and receiver agents;
- ***Model setting 3*****:** Participation probability of 100% and rational behavior of sender and receiver agents;
- ***Model setting 4*****:** Participation probability according to the TDR survey is varied by +/- 10% and +/- 20%, behavior of sender and receiver agents according to the TDR survey;
- ***Model setting 5*****:** Participation probability and behavior of sender and receiver agents according to the TDR survey; changed building zone prices in municipalities affected by the 'popular initiative on second homes'.

In order to reduce random effects and to reach market clearing prices close to the equilibrium, the TDR-ABM was run 100 times and the following results represent the overall average of all runs.

4.4.1 Results of setting 1

In this section we calculated the results for Switzerland and specifically for the canton of Valais.

Results for Switzerland

Table 4-7 and Fig. 4-3 illustrate that in auction 1 there is a supply of approximately 5.6 million TDR corresponding to 19.5 km^2, and a demand of approximately 5.8 million TDR corresponding to 13.3 km^2. Approximately 2.7 million TDR are successfully traded, which means that after the first auction it would be possible to downzone 8.9 km^2 building zone land in the sending area and to develop 5.8 km^2 new building zone land in the receiving area. The smaller area in the receiving area is due to the denser development in this area (the utilization factor in the receiving area is higher than in the sending area). The clearing price in the first auction is 1,165 CHF/TDR, leading to an overall transaction volume of 3.1 billion CHF.

In the successive four auctions the quantity of traded TDR decreases significantly (by 93% between first and second auction) and the clearing price increases on average by 5.1% per auction.

After five auctions, a total of approximately 3.4 million TDR are traded, which means that it would be possible to downzone 11.4 km^2 building zone land in the sending area (36% of the total sending area) respectively to develop 7.4 km^2 new building zone land in the receiving area (36% of the total receiving area).

Table 4-7: TDR market results for Switzerland (setting 1).

Au. No.	**TDR supply**		**TDR demand**		**TDR traded**			**Clear. price**	**Total Vol.**
	Sending area (in km^2)	TDR Quantity	Receiving area (in km^2)	TDR Quantity	Sending area (in km^2)	Receiving area (in km^2)	TDR Quantity	CHF/ TDR	Mio. CHF
1	19.51	5,583,324	13.27	5,767,167	8.88	5.76	2,661,468	1,165	3,101
2	10.63	2,921,856	7.51	3,105,699	0.64	0.42	184,659	1,221	225
3	10.00	2,736,391	7.09	2,921,040	0.50	0.37	139,221	1,269	177
4	9.49	2,597,170	6.72	2,781,819	0.62	0.37	188,131	1,345	253
5	8.87	2,409,039	6.35	2,593,688	0.73	0.44	180,029	1,423	256
All					∑ 11.37	∑ 7.36	∑ 3,353,508	Ø 1,196[a]	∑4,012

[a] weighted average (with traded TDR quantity).

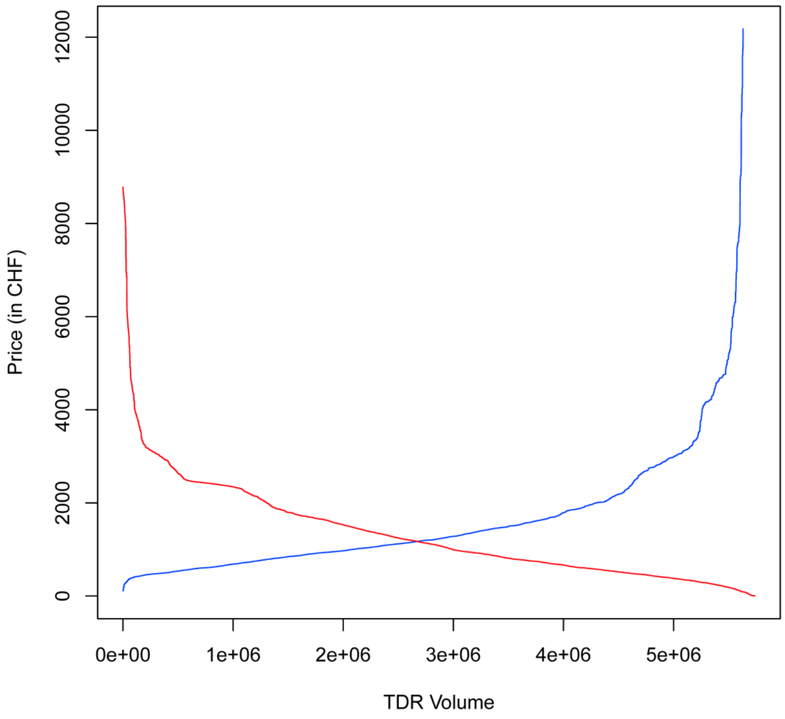

Fig. 4-3: Supply (blue) and demand (red) for TDR in the first auction (setting 1).

Results for the canton of Valais

Because of extraordinarily high supply of undeveloped building zones and low demand for building zones in the canton of Valais (reasons are explained in the introduction of this paper) we analyze the impact of the TDR market here in detail. The model settings are the same as in section above (*Results for Switzerland*).

Table 4-8 illustrates that of the overall trading volume (approximately 3.4 million TDR), 1 million TDR are sold from the canton of Valais, which means that it would be possible to downzone 4 km^2 of building zone land in the sending area of this canton. This is equivalent to around 35% of the total sending area that can be downzoned in Switzerland up to 2018 and 43% of the sending area of the canton of Valais.

Table 4-8: TDR market results for the canton Valais (setting 1).

Au. No.	**TDR supply**		**TDR demand**		**TDR traded**			**Clear. price**	**Total Vol.**
	Sending area (in km^2)	TDR Quantity	Receiving area (in km^2)	TDR Quantity	Sending area (in km^2)	Receiving area (in km^2)	TDR Quantity	CHF/ TDR	Mio. CHF
1	6.18	1,478,357	0.00 (4,477 sqm)	1,025	3.19	0.00	838,697	1,165	977
2	2.99	639,660	0.00 (4,477 sqm)	1,025	0.30	0.00	72,715	1,221	89
3	2.69	566,945	0.00 (4,477 sqm)	1,025	0.05	0.00	9,564	1,269	12
4	2.64	557,381	0.00 (4,477 sqm)	1,025	0.25	0.00	47,156	1,345	63
5	2.39	510,225	0.00 (4,477 sqm)	1,025	0.20	0.00	40,612	1,423	58
All					∑ 3.99	∑ 0.00	∑ 1,008,744	Ø 1,196[a]	∑1,199

[a] weighted average (with traded TDR quantity).

Note that the potential supply and demand values for participation probabilities of 100% are presented in the Table C-1 and Table C-2 in the appendix C.

4.4.2 Results of setting 2

In order to compare the results with agents who behave completely rationally, we simulated the TDR market with the same participation rates as in section 4.4.1, however, with sender and receiver agents who ask, respectively bid the theoretical TDR value. We only present the results of the first auction because it did not seem useful to assume hypothetical adaptation functions[91] for the successive 4 auctions.

The simulation shows that the traded TDR quantity increases with agents behaving rationally (Table 4-9 compared to Table 4-7). It would be possible to downzone approximately 39% more land in the sending area and to develop approximately 39% more land in the receiving area. However, the clearing price would also increase by approximately 25%. The overall money transaction volume would be 5.3 billion CHF.

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[91] We did not assume the same adaptation functions of the TDR survey, because these functions are based on lower ask and higher bid prices in the first auction (possible strategic behavior in the first auction).

It is not surprising that the traded TDR quantity increases with rational agents. In such a market, the agents do not behave strategically in the first auction (e.g. ask high prices in order to maximize the surplus) and therefore the supply and demand curves are not as steep.

Table 4-9: TDR market results for Switzerland (setting 2)[a].

Au. No.	**TDR supply**		**TDR demand**		**TDR traded**			**Clear. price**	**Total Vol.**
	Sending area (in km^2)	TDR Quantity	Receiving area (in km^2)	TDR Quantity	Sending area (in km^2)	Receiving area (in km^2)	TDR Quantity	CHF/ TDR	Mio. CHF
1	19.40	5,572,193	13.06	5,723,953	12.34	7.99	3,635,210	1,453	5,282

[a] Note that the numbers in the first four columns (TDR supply and demand) are not exactly the same as in Table 4-7 because of the randomly chosen agents when considering the agents' participation probabilities.

4.4.3 Results of setting 3

To further investigate the impact of rational behavior in the first auction, we additionally simulated the TDR market with participation probabilities of 100%. The corresponding results are illustrated in Table 4-10 and Fig. C-2 (appendix C). As expected, the traded TDR quantity and the corresponding sending and receiving areas increase. In such a market, 64% (approximately 5.9 million TDR) of the total supply and demand are traded in the first auction.

The resulting clearing price of 1,397 CHF/TDR can be interpreted as the 'theoretical market clearing price'.

Table 4-10: TDR market results for Switzerland (setting 3).

Au. No.	**TDR supply**		**TDR demand**		**TDR traded**			**Clear. price**	**Total Vol.**
	Sending area (in km^2)	TDR Quantity	Receiving area (in km^2)	TDR Quantity	Sending area (in km^2)	Receiving area (in km^2)	TDR Quantity	CHF/ TDR	Mio. CHF
1	31.88	9,174,943	20.49	9,034,348	19.80	12.82	5,856,074	1,397	8,181

4.4.4 Results of setting 4

In order to take into account the uncertainties in the estimation of the participation probability parameters p_{send} and $p_{rerceive}$, we increased respectively decreased these parameters by 10% and 20%, and analyzed the effect of this change on the clearing price and the quantity of TDR traded. We chose to analyze the sensitivity of our results to the participation rates because that parameter is particularly uncertain. In existing TDR programs the participation rate is highly variable and the participation rate obtained from the TDR survey is also uncertain. We know from Pruetz (2003) that the participation rate has a significant impact on the success or failure of a TDR program.

Fig. 4-4 shows the effect of changed participation probabilities on the clearing price (upper number) and the sold TDR quantity (lower number) in the first auction. As expected on ‘typical’ market, the clearing price increases with an increased participation on the demand side and a decreased participation on the supply side. The reverse reaction can be observed with decreased demand and increased supply. Interestingly, the clearing price remains quite ‘stable’ when the participation probabilities are varied by the same percentage (cf. matrix diagonal in Fig. 4-4).

As expected, with increased participation probabilities the sold TDR quantity increases as well. Furthermore, it is interesting to note that with an increased receiver participation probability of 20% and a decreased sender participation probability of 20%, the sold TDR quantity is close to the quantity sold without changing the participation probabilities.

Percentage change of probability to receive

Percentage change of probability to send	**-20%**	**-10%**	**0%**	**+10%**	**+20%**
-20%	1,162 2,102,070	1,221 2,276,556	1,285 2,395,640	1,353 2,505,081	1,411 2,594,867
-10%	1,114 2,201,065	1,164 2,368,739	1,214 2,517,239	1,269 2,627,614	1,335 2,773,712
0%	1,055 2,291,216	1,112 2,473,328	1,165 2,670,143	1,206 2,799,097	1,252 2,941,893
+10%	1,015 2,323,636	1,068 2,539,027	1,122 2,756,340	1,162 2,906,593	1,202 3,062,914
+20%	974 2,370,422	1,032 2,605,367	1,082 2,820,900	1,121 2,993,549	1,167 3,184,962

Fig. 4-4: Effect of a percentage change of parameters p_{send} and $p_{receive}$ on the clearing price (in CHF/TDR, upper number) and the TDR sold quantity (lower number) in the first auction.

Additional figures on the effect on the clearing price and the TDR quantity sold over five auctions are provided in the appendix C (Fig. C-3 to Fig. C-6).

4.4.5 Results of setting 5

In order to investigate the possible impact of the ‘popular initiative on second homes’ on the TDR market (research question 7), we calculated a regression model to estimate the change of building zone prices due to the new restricted percentage of second homes in about 573 of 2,495 municipalities (cf. section 4.1). The reason for our investigation is that different studies (cf. Kaufmann and Rieder, 2012; NZZ, 2012) claim that the building zone prices will decrease due to the initiative, however these studies do not quantify the exact price decline. This might impact on trading prices and quantities.

Excursus: Regression model for building zone prices

As dependent variable for the regression model[92] we chose the price of zones of building land, and as explanatory variables the percentage of second homes and various other socio-economic and topographical variables (including interactions among some variables). The results (descriptive statistics of the variables and model coefficients) are presented in the Table C-3 and Table C-4 in the appendix C and are not further described here.

Based on the estimated model coefficients, we recalculated the building zone price in municipalities affected by the initiative (n=573) by fixing the values of the variable ‘percentage of second homes’[93] to 20%. Then, to take into account the variability in the original building zone prices, we added to the newly calculated building zone prices the model residuals. The estimated effect is shown in Table 4-11. On average the building zone price in municipalities affected by the initiative decreases by 9.4 CHF/sqm. A histogram of this effect (change of building zone prices relative to the original building zone prices) is provided in the appendix C (cf. Fig. C-7).

Table 4-11: Change of building zone prices due to the popular initiative on second homes.

Minimum (in CHF/sqm)	**Maximum (in CHF/sqm)**	**Mean (in CHF/sqm)**	**S.D. (in CHF/sqm)**
-31.47	+8.52	-9.39	+7.75

After having estimated the effect on the prices, we simulated the TDR market with the newly calculated prices. Table 4-12 shows the results of the five auctions and Table 4-13 the differences compared to setting 1.

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[92] The unknown parameters were estimated with the ordinary least squares (OLS) method.

[93] We assume that in the longer term the percentage of secondary residences will decrease to 20%.

The popular initiative on second homes has an effect on the building zone prices and consequently on the TDR market price. However, the effect – especially on the TDR market price – is relatively small and does not significantly change the market results.

Table 4-12: TDR market results for Switzerland (setting 5)[a].

Au. No.	**TDR supply**		**TDR demand**		**TDR traded**			**Clear. price**	**Total Vol.**
	Sending area (in km^2)	TDR Quantity	Receiving area (in km^2)	TDR Quantity	Sending area (in km^2)	Receiving area (in km^2)	TDR Quanti-ty	CHF/ TDR	Mio. CHF
1	19.48	5,586,989	13.13	5,764,488	8.90	5.80	2,693,607	1,148	3,092
2	10.52	2,893,074	7.33	3,070,881	0.58	0.39	164,410	1,211	199
3	9.94	2,728,664	6.94	2,906,471	0.48	0.34	140,731	1,259	177
4	9.46	2,587,933	6.60	2,765,740	0.76	0.45	204,034	1,331	272
5	8.70	2,383,899	6.15	2,561,706	0.64	0.39	177,754	1,399	249
All					∑ 11.4	∑ 7.4	∑ 3,380,536	Ø 1,180[b]	∑3,989

[a] Note that the numbers in the first four columns (TDR supply and demand) are not exactly the same as in table 7 and 9 because of the randomly chosen agents when considering the agent’s participation probabilities.

[b] weighted average (with traded TDR quantity).

Table 4-13: Change of market clearing price in setting 5 compared to setting 1.

Auction number	**Clearing price setting 1 (in CHF/TDR)**	**Clearing price setting 5 (in CHF/TDR)**	**Absolute difference (in CHF/TDR)**	**Percentage difference**
1	1,165	1,148	-17	-1.5%
2	1,221	1,211	-10	-0.8%
3	1,269	1,259	-10	-0.8%
4	1,345	1,331	-14	-1.1%
5	1,423	1,399	-24	-1.7%

4.5 Discussion

The results showed that the ‘rationality’ (cf. definition in section 4.4) of the agents regarding their participation and their offered and bid prices influences the market clearing price and the TDR quantity sold. In a TDR market with agents behaving according to the TDR survey, which differs from (purely) rational, the clearing price in the first auction was on average approximately 25% lower than in a market with rational agents. However, both market clearing prices (with rational and limited rational behavior) were in the range of currently existing land prices[94] and indicated that the model produced realistic outcomes. This comparison of prices resulting from the simulation and market prices may be considered as one validation of our model. We have resorted to this form of validation, as validating agent-based models that represent social systems is extraordinarily difficult (Louie and Carley, 2008; Schutte, 2010) or indeed impossible (Oreskes et al., 1994) due to a lack of physical laws.

Since the selection process of both sender and receiver agents is random – except for the simulation of 100% participation probabilities, different agents participate in the TDR market. For this reason, we chose to run each simulation setting 100 times. This helped to reduce random effects and to reach prices close to the equilibrium.

In order to consider the uncertainties of the stated probability to participate (TDR survey), we varied them by 10 and 20%. This is justified by highly varying participation probabilities in existing TDR programs (cf. e.g. Pruetz, 2003) and by the fact that in a ‘real’ implementation of a TDR market the willingness to participate might be higher because of better information through the use of additional diffusion or communication instruments, or through self-diffusion effects (cf. e.g. Kaufmann-Hayoz and Gutscher, 2001). Moreover, the variation of these parameters (p_{send} and $p_{receive}$) can be seen as a form of sensitivity analysis of the model[95].

We did not implement any learning processes of the agents. According to Duffy (2006), learning processes are a function of the agents’ information and their cognitive abilities. Applied to our case, an example of learning would be that the agents determine the TDR price as a function of the market clearing price in the previous auctions. Due to the TDR survey which asked simultaneously for all prices of asks and bids in all five auction rounds, we had no empirical data to quantify and verify the learning process regarding the market clearing prices. Another learning example would be imitating

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[94] We compared the market clearing prices with current land prices, that is, the prices that take into account the building area that potentially can be developed on a parcel. According to Wüest and Partner (2011) current prices for Switzerland are in the range of 1,150 to 1,600 CHF/sqm. This value has been calculated by dividing the building zone prices (average price residential zone (single and multiple-family houses)) by realistic average utilization factors (e.g. 0.25 to 0.35) (cf. definition of TDR quantity per parcel in section 4.3.3).

[95] A more detailed sensitivity analysis of the parameters p_{send} and $p_{receive}$ can be found in chapter 2 (section 2.4.2).

the behavior of other agents in the ‘neighborhood’. However, in economics there is – in contrast to psychology – no general model that describes imitation (Brenner, 2006). Because of this lack and the challenges related to implementing imitation models from psychology, we did not consider imitation or other learning processes in this version of the simulation[96].

Moreover, it should be noted that the TDR survey did not consider the opportunity costs[97] of both senders and receivers, and therefore these costs are ignored in the simulation as well.

When it comes to political implications of the simulation, the following points should be made: In Switzerland at present two ideas to reduce the existing large and undesirable building zone areas (for which there is no demand) are discussed: 1) introducing a zoning tax on newly designated building zones and using the income to compensate for downzoning; 2) introducing a TDR market as proposed in this paper.

The TDR market provides a number of advantages compared with a zoning tax[98]. The main advantage is that it would be applied for the whole of Switzerland involving the same conditions for all landowners and people intending to develop a parcel of land. The zoning tax, on the contrary may vary and be levied separately in each canton, possibly even in each municipality. Also the political will to downzone might vary. Nevertheless, in a TDR market an additional financial compensation between the cantons and municipalities should be organized as there will be quite unequal financial flows, i.e. flows from urban areas to rural areas in those places where the authorities (with administrations that) did not follow the Swiss planning rules and hence are now disposing of too large building zones.

Another advantage of the TDR market relative to the zoning tax is that the landowners who benefit from zoning up their parcel (receivers) would hardly benefit from the windfall gains of zoning, whereas in a system of zoning tax only a part (e.g. min. 20% of the planning gain following a new national law proposal) of the planning gain would be captured. Hence, the TDR market concept might be a stronger incentive for high density development, as TDR have to be bought according to the set utilization factor which gives land owners an incentive to build more densely.

In a further difference to the zoning tax, the TDR market mechanism allows for a ‘direct’ financial flow between the sending and receiving area, whereas, with a zoning tax, the state would have to advance money in order to compensate the downzone of a parcel (e.g. in the form of a compensation fund) because the tax would be levied only when the parcel is sold or developed following the national law proposal.

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[96] For more information about behavior models with learning processes see e.g. Brenner (2006) and Duffy (2006).

[97] The opportunity costs for the senders would be the value of the parcel as agricultural land and for receivers the value of the parcel as building zone land without TDR.

[98] Also known as tax on planning gains.

In order to analyze the possible effect of the popular initiative on second homes on the TDR market, we estimated a regression model of land prices, including as explanatory variable the proportion of second homes. In order to recalculate the building zone prices we assumed that, in the longer term, in municipalities affected by the initiative the percentage of second homes will decrease to 20%. It is worth stating that this assumption introduced an additional uncertainty in the simulation results.

To facilitate social housing – which is repeatedly discussed in Switzerland – in a practical implementation of a TDR market, housing cooperatives could be favored by reducing the number of TDR needed to develop a parcel in the receiving area. This could easily be implemented by a 'reduction factor' of e.g. 0.5 in the calculation of the TDR quantity needed per parcel (e.g. eq. 4-1). The effect of such a reduction might be relatively small regarding the TDR price since cooperatives and other social organizations own only a small percentage (4%) of land in the building zone (cf. chapter 3, section 3.2.2; Gerheuser, 2004) and will continue to do so in the future based on our assumed extrapolation of ownership.

In the TDR-ABM we did not consider the recently adopted[99] 'popular initiative on agricultural (cultural) land' in the canton of Zurich. Following this initiative it is no longer possible to designate new building zones for the cultural land classes 1-6 or land that is classified as ecologically valuable. For our simulation, this implies that we should theoretically cap the whole demand (receiving area) in the canton of Zurich. However, we did not implement this restriction for two main reasons: a) we assume that a large part of the demand in the canton of Zurich will shift to surrounding cantons, and in this case – because of the increased demand – most agents will probably behave similarly as in the canton of Zurich, and b) the exact implementation as a law is currently still under way.

4.6 Conclusions

The main contributions of this paper in relation to previous work on TDR in Switzerland (e.g. cf. ARE, 2006; Gmünder, 2004, 2010) are that we analyzed the impact of a potential TDR market with realistic data and behavior of landowners collected in the TDR survey. Moreover, as far as we know, it is the first agent-based model that simulates a TDR market.

The findings concerning our research questions can be summarized as follows: (1) Depending on the market participation probability and the rationality of the agents, the TDR market price was in the range of 1,165 to 1,453 CHF/TDR. The TDR prices were all comparable to current land prices in Switzerland (market prices)[94]. The overall money transaction volume would be approximately 4 bil-

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[99] Adopted on 17 June 2012. For more information see: http://www.zh.ch/internet/de/aktuell/news/medienmitteilungen/2012/185_kulturlandinitiative.html, accessed: 2012-09-27.

lion CHF. (2) Under the assumption that the agents behave according to the TDR survey, the TDR market prices increased on average by 5.1% during the five auctions. (3) After five auctions and under the assumption that the agents behaved according to the TDR survey, a total of 3.4 million TDR were traded. This would allow the downzoning of 11.4 km^2 building zone land in the sending area[100] and the development of 7.4 km^2 new building zone land in the receiving area[101] up to 2018. Hence, the overall building zone area would decrease. (4) Under the same assumption as in (3), in the specific canton of Valais it would be possible to downzone 4 km^2 of building zone land of its sending area until 2018[102] which is equal to 43% of the sending area of the canton of Valais. (5) If the agents behaved fully rationally, the TDR market price would increase to a) 1,453 CHF/TDR with participation probabilities according to the TDR survey and b) to 1,397 CHF/TDR with participation probabilities of 100%. In a) the traded TDR quantity in the first auction would be 3.6 billion TDR, in b) 5.9 billion TDR. (6) The TDR market price remained quite stable when both sender and receiver participation probabilities changed with the same rate. In contrast, the market price increased with higher receiver participation probabilities (more demand than supply) and decreased with higher sender participation probabilities (more supply than demand). (7) The popular initiative on second homes had a slightly negative effect on the building zone price (decrease on average: -9.4 CHF/sqm) and consequently influenced the TDR market price to a small degree. The TDR market price decreased on each of the five auctions on average by 1.2%.

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[100] 11.4 km^2 are approximately equivalent to the total area of the city of Kreuzlingen (second largest city in the canton of Thurgau) or to the total building zone area of the city of Sion (largest city in the canton of Valais).

[101] 7.4 km^2 are approximately equivalent to the total residential zone area of the canton Basel-Town.

[102] 4 km^2 are approximately equivalent to the total building zone area of the city of Baden or Delémont.

5 General conclusions

The thesis is presented in three chronologically and thematically linked scientific papers. Its main findings and research caveats are summarized in this chapter. In addition, ideas for further research, as well as general recommendations and factors for success for the implementation of a TDR market in Switzerland are provided.

The **first paper** (Chapter 2) presented a possible design for a TDR market in Switzerland and based that on an agent-based model for simulating the TDR market. The concept for the market design was defined and elaborated in two expert workshops. The workshops took into account both the unique Swiss situation and experience in other countries. Due to the fact that a conceptual design alone cannot assess the impact of a practical implementation, a simulation framework for the TDR market was developed.

The discussion in the two expert workshops, as well as the literature study on existing TDR programs (cf. e.g. Janssen-Jansen et al., 2008; Kopits et al., 2005; Pruetz, 2003), have shown – among other details of the TDR market concept – that the TDR instrument should be implemented as a dual-zone program, specifying both a 'sending' and a 'receiving area', and capping the existing building zones (following the cap-and-trade principle). Regarding the sending and receiving areas, the experiences in the TDR programs in the USA have demonstrated that the designation of appropriate sending and receiving areas is essential for the success of a TDR market (Pruetz, 2003). In Switzerland, the designation of these areas respective parcels would ideally be done by the cantons and in detail by the municipalities. In order to prevent a rampant building boom in the receiving area and to keep the supply and demand in balance, it is recommended to designate the sending and receiving areas at given intervals. The market area should cover the whole country, because of the considerable differences in supply and demand of building zones.

Following another recommendation by Swiss planning experts, the number of TDR per parcel was defined as the building area that can be potentially developed on a parcel (parcel area multiplied by the utilization factor[103]). In addition, the TDR per parcel can only be sold or purchased as a whole package (fixed TDR bundle). This restriction should promote high density development in the receiving area[104]

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[103] Assuming an identical definition of the utilization factor (Germ: „Ausnützungsziffer") throughout Switzerland.

[104] The receivers have to buy TDR for the maximum allowable gross floor area. This is an incentive for high density development.

and compensate the loss of the development possibility in the sending area. Also, it should reduce the numbers of transactions, and consequently the transaction costs[105].

Furthermore, the experiences in other TDR programs have shown that the success of a TDR market is related to the existence of a trading platform (also known as ‘TDR bank’; cf. Kaplowitz et al., 2008). Such a platform facilitates the trade of TDR and the transaction costs can be kept low. Another advantage is that the trust in such a program will be significantly higher (Kaplowitz et al., 2008; Machemer and Kaplowitz, 2002; Pruetz, 2003). In Switzerland, most likely the Federal Office for Spatial Development would operate the trading platform, as well as monitor the system, define the detailed trading rules and also act as a ‘market maker’ or search for a private one. The latter would ensure the liquidity of the market and offset any market imbalances (e.g. lack of TDR demand; cf. Radcliffe, 1997).

The analysis of the theoretical discussions and experts’ opinions led to the conclusion that an auction is an ideal price determination mechanism, and this for one main reason: There is no previous information about the willingness to pay or price expectations of the potential market participants. According to Krishna (2002) such uncertainties of both sellers and buyers are an inherent characteristic of auctions. In an auction both the allocation of the traded good and price determination are based on the bids of the market participants. Auctions are flexible pricing mechanisms to determine the market price by exhausting the willingness to pay and reflecting price expectations of the participants (McAfee und McMillan, 1987; Skiera und Revenstorff, 1999).

For the TDR market, a multi-unit double auction (MDA) with a uniform price turned out to be appropriate. In this type of auction, the landowners in the sending area (TDR supply) can submit asks (offers) with the desired price per TDR, and the landowners in the receiving area (TDR demand) can submit bids with the price they are willing to pay for the needed TDR. According to the rules of the MDA (cf. chapter 2, section 2.2.3), the asks are sorted price ascending, the bids price descending, and a uniform TDR market price is calculated. It is the price at the intersection of the ask- and bid-curves. An essential advantage of this double (two-sided) auction, compared to a one-sided auction with a fixed supply, is that the ‘sensitivity’ to the so-called demand reduction problem (also known as bid shading; cf. e.g. Ausubel and Cramton, 2002; Krishna, 2002) is reduced. That is, the market clearing price would decrease less rapidly in the case of bid shading.

Following further results of the two experts’ workshops and literature findings, for the Swiss TDR market it is useful running two rounds of five auctions, with one year between each auction. The total time required to organize five auctions (=5 years) gives municipalities time to adapt their zoning plans,

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[105] We mean costs associated with the exchange of goods or services, including information, negotiation, communication and control costs.

i.e. designate sending and receiving areas, for the next round. It should be noted that in a practical implementation of a TDR market this proposal might be adapted, dependent on the practical experience that will be made.

Regarding banking and borrowing of TDR, in the Swiss TDR market this should not be allowed. Banking and borrowing might have a negative impact on both the cost-effectiveness (Henger and Bizer, 2010) and market liquidity. Moreover banking and borrowing might be an incentive for strategic behavior and decrease the public confidence in a TDR market.

Based on the TDR market concept, a suitable agent-based simulation model was developed (TDR-ABM). The model simulates a ‘true order book’ in which agents (here landowners) submit asks and bids for the ‘good’ TDR. The main advantage of the ABM is that rational behavior of the agents need not to be assumed as is usually the case in economic models. Here, three different agent types with specific state variables, behavior and adaption rules were implemented. For the two agent types representing landowners (sender and receiver agents) four[106] landowner categories (e.g. enterprises) were distinguished, with the assumption that each would behave differently.

Since the TDR bundles would be traded at fixed and different package sizes, in the TDR-ABM a quite unique price determination procedure was implemented: the last successful order (ask or bid) at the intersection of the supply and demand curve needed – in most of the cases – to be split. However, because at maximum one TDR bundle would be affected, the resulting efficiency loss would be insignificantly small. The loss by implementing another option, e.g. a two-sided Vickrey auction (cf. chapter 2, section 2.2.3), would be on the assumption that a market participant can own more than one parcel – considerably higher. In addition, it should be noted here, that overall there is no efficient[107] and at the same time budget-balanced[108] market (Fudenberg and Tirole, 1991; Huang et al., 2002; Myerson and Satterthwaite, 1983).

First tests on the suitability of the TDR-ABM were conducted through a computational performance analysis and a sensitivity analysis of selected parameters. These tests, as well as an additional face validation (cf. e.g. Klügl, 2008; North and Macal, 2007), have shown that the model is fit to be further developed by incorporating empirical data.

The **second paper** (chapter 3) presents a questionnaire survey that was specifically designed to calibrate the TDR-ABM. Therefore, a special approach was chosen: Each single questionnaire stated a

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[106] Because of the small sample size for the category of cooperatives (cf. statistical analysis in the second paper), in the final agent-based model, only three landowner categories were distinguished.

[107] An efficient market favors neither buyers nor sellers, and aims to maximize the collective profit (surplus of buyers and sellers).

[108] In a budget-balanced market, the sum of payments of buyers are equal to the revenues of sellers.

unique realistic situation description that was based on existing land registry and transaction data of building zone parcels. The objective was to calculate for each distinguished agent type and landowner category separate statistics (e.g. probability to participate, regression model for TDR price determination etc.). A central and important advantage of this approach was the implicit data variability that allowed the calculation of various regression models. However, a drawback of the questionnaire survey, compared to e.g. economic experiments, was that the resulting market clearing prices in each of the auctions could not be considered in the questions regarding the asks (bids) of the successive auctions. Therefore, it was only possible to calculate simple functions for the adaptation behavior during the five auctions. For a first calibration of the TDR-ABM this seemed to be appropriate, however, in a later version of the model this simplification could be improved (cf. section 5.1). Another disadvantage was that in a questionnaire survey there is no possibility to check back on potentially wrong responses due to misunderstandings of a complex topic.

For the survey it was decided to contact spatial planning and real estate professionals, instead of a random sample of all existing and potential landowners. The reasons were the complex topic and the previous lack of public information and debate about TDR. A total of 1,976 professionals – divided into four landowner categories – throughout Switzerland were contacted. Since the number of each contacted landowner category was based on the landowner structure from existing land registry and transaction data, the sample size varied considerably between the distinguished landowner categories (e.g. small sample size for cooperatives). Furthermore, the response rate (16.75%) was quite low and pointed to a possible scepticism towards the new instrument (e.g. because of lack of information, strategic behavior etc., cf. e.g. Gmünder, 2010). It might be that the response rate could have been raised through special measures or incentives (e.g. prior recruitment through a telephone survey). However, it may be assumed that in a ‘real’ implementation of the TDR market the willingness to participate might be significantly higher. Possible reasons are: use of additional diffusion or communication instruments (e.g. reports in newspaper) or self-diffusion effects (target people have an effect – voluntary or not – on the behavior of others, cf. Kaufmann-Hayoz and Gutscher, 2001).

A plausibility test was carried out in order to eliminate possible wrong answers and therefore to prevent model misspecifications, biased parameter estimations and incorrect results. Although such a test was undoubtedly necessary to obtain reliable results, it further decreased the sample size. Therefore, the results – especially the ones for the landowner categories of enterprises and non-profit institutions (NPI) – should be treated with caution.

The main findings of the questionnaire survey can be summarized as follows: The willingness to participate in the TDR market varied among the distinguished landowner categories. It is striking that the NPI (cantons, municipalities and cooperatives) were barely willing to participate (29.5% as sender;

16.7% as receiver), in contrast to the representatives of private persons (RPP) who were most willing to participate (55.9% as sender; 60.8% as receiver) in the TDR market. The most important reasons for not participating were, according to the replies, the overly complicated TDR instrument and the high transactions costs.

Regarding the criteria when determining the ask (bid) price for the TDR, for all owner categories the building zone price prior to the introduction of TDR seemed to be the most important one. This result was also reflected in the regression model for determining the TDR price (ask and bid) in the first auction: it was mostly determined by the theoretical TDR value which in turn is a function of the building zone price, agricultural zone price and the utilization factor. Differences in determining the TDR price among the landowner categories could only be found in the receiver categories NPI and RPP. However, because of the above-mentioned small number observations in the NPI category, this finding should be treated with caution.

In the workshop with spatial planning and real estate experts, it was recommended to consider a location factor in the calculation of the number of TDR per parcel. Depending on the location of the parcel, this factor would then increase or decrease the number of TDR. Interestingly, in the questionnaire survey the location factor – reflected in the proposed prices – had no or just a slight influence on the price that a landowner would ask or pay for the TDR bundle of a parcel. It can be concluded that the landowners seemingly had an idea of how much to ask (bid) for the parcel as a whole, and as a result they changed their prices according to the number of TDR per parcel. Although the location factor was ignored in the final simulation runs, it is worth stating at this point that such a factor would reduce the variance between the asks and bids, and therefore also the corresponding sender and receiver surpluses (cf. Fig. 2-7 in chapter 2). This might be advantageous, especially regarding the problem of rewarding so-called ‘planning errors in the past’ (oversupply of building zone areas (and therefore TDR) in rural municipalities caused by permissive zoning practices, cf. section 2.1)

Concerning the price adaptation during the five auctions, it was found that the landowners in the sending area (senders) adapt their ask prices linearly and the landowners in the receiving area (receivers) exponentially. Among the senders, the ask price was most adapted (reduced) by RPP, then by NPI and least by enterprises. A statistically significant difference could only be found between enterprises and the other two categories. The greatest adaptation (increase) among the receivers was found in the NPI category, then in the RPP, and the lowest adaptation was observed by enterprises. Here, only a statistically significant difference between enterprises and NPI was found. What is striking on both sides of the market is that seemingly the enterprises adapt their prices during the five auctions least.

The **third paper** (chapter 4) presents the empirically calibrated agent-based TDR market simulation (TDR-ABM) and the results of five different simulation settings. The calibration was done through integrating the detailed survey results, i.e. the identified probabilities to participate in the TDR market and the calculated regression models for the ask (bid) price determination and adaptation. The five different model settings allowed an analysis of relevant political and economic questions for Switzerland.

The simulation results showed that the ‘rationality’ of the agents influenced the market clearing price and the TDR quantity sold. It was found that in a TDR market with agents behaving according to the TDR survey, which differs from rational agents, the clearing price in the first auction was on average approximately 25% lower than in a market with (purely) rational agents. However, it was also shown that both market clearing prices – with rational (1,397 CHF/TDR) and limited rational behavior (1,165 CHF/TDR) – were in the range of currently existing land prices. Therefore, a major criticism by Schläpfer (2007), who claimed that TDR might result in negative societal impacts, e.g. scarcity and higher prices for land, could be disregarded.

Due to the fact that existing TDR programs (cf. e.g. Pruetz, 2003) observed highly varying participation rates, and that in a ‘real’ implementation of a TDR market the willingness to participate might be higher compared with the survey (cf. explanations above), one model setting investigated the impact of varying participation rates (+/- 10 and +/- 20%). The most important result for this setting was that the TDR market responded as expected in a ‘typical’ market (e.g. increasing clearing price with increasing demand). In addition, it could be demonstrated that the market price remained quite ‘stable’ when participation probabilities of sender and receiver agents were varied by the same percentage.

Moreover, it could be shown that – under the assumption that the agents (landowners) behave according to the TDR survey – it would be possible to downzone approximately 11.4 km^2 building zone land in the sending area and to develop 7.4 km^2 new building zone in the receiving area up to the year 2018. As a consequence, the absolute area of building zone land would decrease (because of the denser development in the receiving area). The greatest reduction of the building zone area (4 km^2) would be reached in the canton of Valais.

Under the same agents’ behavior assumption, the overall transaction volume would be in the first auction approximately 3.1 billion CHF, and after five auctions approximately 4 billion CHF. The small increase of the transaction volume from the first to fifth auction results from the quite small price adaptations (asks, bids) during the five auctions. This might also be a reason for the slight increase of the market clearing price during the five auctions (on average approximately 5% increase).

In comparison, if all agents participated in the TDR market with participation probabilities of 100% and behave rationally (ask/bid the theoretical TDR value), it would be possible to downzone approximately 19.8 km^2 building zone land in the sending area and to develop 12.8 km^2 new building zones in the receiving area after the first auction. The so obtained market clearing price – which can be interpreted as the ‘theoretical market clearing price’ – was 1,397 CHF/TDR, and the overall transaction volume in the first auction increased to approximately 8.2 billion CHF. Note that the simulation covers the period up to 2018 and the quantity of supplied and demanded TDR is based on various calculations and demand extrapolations from Fahrländer Partner (2008).

Finally, in the fifth model setting, it was investigated whether the ‘popular initiative on second homes’ might impact on TDR trading prices and quantities. For this purpose, a regression model that estimated the change of building zone prices due to the newly restricted percentage of second homes was calculated. The TDR market was simulated with the newly calculated land prices and it could be demonstrated that the ‘popular initiative on second homes’ would only have a slight influence on the TDR market price.

Two major caveats of the findings presented in chapter 3 might be important to note: First, the agents’ behavior was calibrated quite simplistically, for instance no learning algorithms were included or any strategic behavior. Second, the data used for the calculation of the number of agents and the agents’ properties was slightly outdated[109].

To conclude, the thesis presented the first agent-based model that simulates a TDR market. The simulation results demonstrated that in Switzerland, the market-based instrument of transferable development rights could be a useful instrument to both reduce the building zone area and address the problem of the spatial imbalances in supply and demand for these zones. However, it should not be forgotten, that the TDR market is ‘supplementary to planning’. A TDR market program depends on established planning measures, namely the designation of the sending and receiving areas, which should be in accordance with planning criteria.

5.1 Further research

In what follows, a brief outline of possible ideas for developing this work is presented: First, the calibration of the TDR-ABM could be improved by collecting more information about the behavior of the agents. For example, a role playing game or economic experiments might be appropriate approaches to investigate the influence of past market clearing prices on the asks (bids) at following auctions. These approaches might also be used to explore whether there are imitation effects among the agents or other learning processes.

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[109] In order to calculate the supply and demand of TDR, data from 2007 (ARE, 2008; Fahrländer Partner, 2008) were used, because no newer data were available. Also other data used (e.g. for calculating the agents’ properties) could be updated in the meantime.

Second, the quality of the data used to calculate the number of agents and their properties (e.g. parcel area) could be enhanced as well. In January 2013, the newest Swiss statistics on building zones (German: “Bauzonenstatistik”) were published[110]. The integration of these data, as well as other data on building zone parcels (e.g. newest building zone prices, cf. Wüest und Partner AG, 2012), could further update the TDR-ABM simulation results.

Third, in the proposed TDR market concept, the sending area needs to be designated by the municipalities in accordance with existing Swiss spatial planning principles. All parcels in this designated sending area are defined for downzoning which means that landowners in this area receive TDR which, however, they lose at the end of the trading period (the duration of the auction) if not sold. An alternative that could be further investigated would be to place the complete undeveloped building zone into the sending area, to allocate TDR to all landowners and to let them decide who wants to sell and who wants to keep the development rights. This would have the advantage of letting the market decide which parcels will be downzoned and would avoid discrimination between the landowners in the undeveloped building zone. However, the disadvantage of this alternative might be that unbuilt sections between settled areas result. Furthermore, a mechanism would have to be devised to make sure that the desired share of the undeveloped building zone is downzoned.

Fourth, in the thesis the exact implementation of the potential TDR market within the existing Swiss law was only briefly addressed[111]. Therefore, an in-depth legal investigation (incl. possible taxation of the TDR) is needed before the TDR instrument could actually be implemented.

Fifth, beyond the legal investigation, the research could be further extended by outlying all details of a possible monitoring system and by estimating the transaction costs[112] incurred in trading the TDR. Concerning the latter, it could e.g. be analyzed whether it is useful to weight potential TDR-fees relative to the value of a transaction or not.

Sixth, in order to take into account the unequal financial flows between municipalities and cantons due to TDR transactions, it could be investigated whether TDR program-flows could be taken into account in existing financial compensation schemes and how or whether a separate solution might be more appropriate, and if so, which.

Seventh, instead of a trade between individual landowners, the effect of restricting the TDR trade to municipalities could be analyzed. In such a market, the municipalities would sell (buy) all TDR and

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[110] For more information see: http://www.are.admin.ch/themen/raumplanung/00236/04878, accessed: 16-01-2013.

[111] According to Epiney (2003), TDR are in principle compatible with the Swiss legal system, however, at least the Swiss Federal Law on Spatial Planning has to be revised.

[112] Costs associated with the exchange of goods or services, including information, negotiation, communication and control costs.

the individual landowners would be compensated (charged) with the theoretical TDR value (cf. section 3.3.1, eq. 3-1). Assuming that the municipalities would sell the TDR at a price above the price they have paid, such an approach would generate revenues for the municipalities (and cantons), especially in the regions with low land prices. However, the TDR-market price might increase.

To conclude, in chapter 2 (section 2.5.1) it is suggested that at the end of the TDR program it could be replaced by a TPP (Tradable Planning Permits) program. In such a follow-up program, the Federal Office for Spatial Development would define a predetermined total permit quantity of TPP for designating new building zones. This total quantity would be distributed – according to a defined distribution formula – to the municipalities which could then trade the TPP amongst each other. Here, further research would be e.g. required for the calculation of such a distribution formula.

5.2 General recommendations and factors for success for the implementation of a TDR market in Switzerland

In what follows, general recommendations and factors for success for the implementation of a TDR market in Switzerland are outlined. The points proceed from the main findings of the thesis and are additional to conclusions in the existing literature (cf. Janssen-Jansen, 2008; Machemer and Kaplowitz, 2002; Pruetz, 2003)[113].

1) The results of the TDR survey showed a low willingness to participate in the TDR market. Reasons were the complex topic and possibly the previous lack of public information and debate about TDR. Therefore, in a practical implementation of a TDR program, the public respectively the potentially involved landowners need to be fully informed and instructed for their participation.

2) In order to consider the whole of Switzerland as a market area – which will be necessary due to the imbalanced supply and demand for undeveloped building zones – sending and receiving areas need to be designated in all regions. Only in such a case would it be possible to transfer development rights, i.e. TDR, from regions with low utility of land to regions with high utility. The sending and receiving areas should first be designated by the cantons, and then in detail by municipalities following overall uniform criteria. All political authorities should consider the same planning principles.

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[113] In the introduction of the first paper (chapter 2) some factors for success from the existing literature are mentioned.

3) The simulation results showed that in order to keep the TDR market price stable, the TDR supply and demand should be approximately equal. That is, the differences between supply and demand – due to variations in the willingness to participate of the landowners or due to differences in the designation of parcels by the municipalities – should not exceed 10-15%. In the simulation the supply and demand of TDR was determined by the demand for building zones in the next five years.

4) Furthermore, the simulation results confirmed that the proposed multi-unit (fixed package sizes) double auction with a uniform price is particularly suitable as a price formation mechanism for the trade of TDR. The resulting market clearing prices were comparable to existing land prices and they did not over- or undershoot. Hence, this kind of auction may be adopted.

The next points could not be considered in the simulation, however, in a practical implementation of a TDR market, they might be important.

5) In order to encourage the market participants to bid more truthfully, it was suggested to run one auction per year. In a practical implementation of a TDR market this proposal might be adapted, depending on the practical experience that will be made.

6) At the beginning of the TDR trade, it is suggested to support the trade with a public (e.g. Federal Office for Spatial Development) or private 'market maker'. To run the simulation a 'market maker' was not needed, however, in practice, a 'market maker' could ensure the liquidity of the market and offset any market imbalances (e.g. lack of TDR demand).

7) Practical experiences (e.g. auctioning rights to vehicle ownership in Singapore[114] or auctioning tariff quotas of agricultural products in Switzerland[115]) have shown that an 'electronic account' might be useful for a functioning trading system and to increase the public confidence. Therefore, it is suggested that all landowners who are willing to participate in the TDR market need to open a 'TDR-account'. After opening the 'TDR-account', the landowners in the sending area would receive their TDR to sell (free allocation), and the landowners in the receiving area would be allowed to buy the TDR they need. The 'TDR-account' might be incorporated into the future national electronic property information system eGRIS[116].

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[114] For more information see: https://ocoe.lta.gov.sg, accessed: 12-06-2012 or Chu, S. (2002).

[115] For more information see: http://www.blw.admin.ch/themen/00007/00059 or https://eversteigerung.ssl.admin.ch, accessed: 12-06-2012.

[116] For more information see: http://www.egris.info, accessed: 11-27-2012. eGRIS stands for "elektronisches Grundstück-Informationssystem" (electronic property information system).

8) In order to increase market efficiency, the transaction costs should be kept as low as possible[117]. This might be achieved with simple and clear trading rules, and through a centralized provision of information. Good information might also reduce the need for ‘brokers’ or other ‘advisers’ helping to trade the TDR, which in turn reduces the overall costs. Moreover, the trade could be made free of charge. A fee might be levied however for opening the ‘TDR-account’ in order to make sure only serious agents (landowners) participate.

9) Because of the quite unequal financial flows between the cantons and municipalities additional financial compensation could be considered (e.g. consideration of the TDR trade in the existing federal compensation scheme).

10) At the end of the TDR program (e.g. when 90% of the TDR are sold), the political authorities should have a solution or at least a proposal for a follow-up program (e.g. TPP program).

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[117] For more information about the effect of transaction costs on the market efficiency in double auctions see e.g. Jamison and Plott (1997) or Noussair et al. (1998).

6 References

An, L., Linderman, M., Qi, J., Shortridge, A., Liu, J., 2005. Exploring complexity in a human-environment system: an agent-based spatial model for multidisciplinary and multiscale integration. Annals of the Association of American Geographers 95, 54-59.

ARE, Federal Office for Spatial Development, 2005. Raumentwicklungsbericht. Bern.

ARE, Federal Office for Spatial Development, 2006. Flächennutzungszertifikate Systemdesign und wirtschaftliche Auswirkungen. Bern.

ARE, Federal Office for Spatial Development, 2008. Bauzonenstatistik Schweiz 2007. Bern.

Ausubel, L. M., Cramton, P., 2002. Demand reduction and inefficiency in multi-unit auctions. Working Paper, University of Maryland.

Axhausen, K.W., Weis, C., 2010. Predicting response rate: a natural experiment. Survey Practice, http://surveypractice.wordpress.com/2010/04/14/predicting-response-rate (accessed: 2012-06-26).

Avenir Suisse, 2012. Die 8-, 9-, 10-Millionen-Schweiz. avenir aktuell 03/2012.

Bădică, C., Bădiță, A., Ganzha, M., 2006. Implementing rule-based mechanisms for agent-based price negotiations. SAC ’06, 23-27 April, Dijon, France.

Batty, M., 2005. Cities and Complexity: Understanding Cities with Cellular Automata, Agent-based Models, and Fractals. The MIT Press, Cambridge, MA, USA.

Baumgartner, F., 2005. Siedlungsentwicklung in der Kostenfalle. Tec 21 (14-15), 4-8.

Ben-Gal, I., 2005. Outlier Detection. In: Maimon, O., Rockach, L. (Eds.), Data mining and knowledge discovery handbook: a complete guide for practitioners and researchers. Kluwer Academic Publishers, Dordrecht (NL).

Berger, T., Goodchild, M., Janssen, M.A., Manson, S.M., Najlis, R., Parker, D.C., 2002. Methodological considerations for agent-based modeling of land use and land-cover change. In: Parker, D. C., Berger, T., Manson, S.M. (Eds.), Agent-based Models of Land Use and Land Cover Change. LUCC Report Series No. 6, LUCC Focus 1 Office, Indiana University, Bloomington, IN, USA, pp. 7-25.

Berninghaus, S.K., Ehrhart, K.-M., Güth, W., 2006. Strategische Spiele: Eine Einführung in die Spieltheorie (2. Auflage). Berlin, Heidelberg, Springer.

Bourbassa, S.C., Hoesli, M., Scognamiglio, D., Zhang, S., 2010. Land leverage and house prices. Swiss Finance Institute Research Paper Series 10-48.

Bousquet, F., Le Page, C., 2004. Multi-agent simulations and ecosystem management: A review. Ecological Modelling 76, 1-8.

Brenner, T., 2006, Agent learning representation: advice on modelling economic learning. In: Tesfatsion, L., Kenneth, L. J. (Eds), Handbook of Computational Economics. Elsevier, B. V., Amsterdam, pp 896-922.

Brown, D.G., Robinson, D.T., 2006. Effects of heterogeneity in residential preferences on an agent-based model of urban sprawl. Ecology and Society 11 (1), 46, http://www.ecologyandsociety.org/vol11/iss1/art46 (accessed: 2012-05-16).

Brownstone, D., Golob, T., 2009. The impact of residential density on vehicle usage and energy consumption. Journal of Urban Economics 65 (1), 91-98.

Brueckner, J.K., 2000. Urban sprawl: diagnosis and remedies. International Regional Science Review 23(2), 160-171.

B,S,S. Volkswirtschaftliche Beratung, 2011. Konzepte zur Bauzonenverkleinerung: Abklärung der monetären Folgen und der Wirksamkeit von vier verschiedenen Konzepten. Basel.

Chan, N.T., LeBaron, B., Lo, A.W., Poggio, T., 1999. Agent-based models of financial markets: a comparison with experimental markets. MIT working paper, MIT Department of Electrical Engineering and Computer Science, Cambridge, MA, USA.

Chomitz, K.M., 2004. Transferable development rights and forest protection: An exploratory analysis. International Regional Science Review 27(3), 348-373.

Chu, S., 2002. Auctioning rights to vehicle ownership: Singapore's experience with sealed-bid tenders. Transportation Research Part A 36, 555-561.

Conrad, J.M., LeBlanc, D., 1979. The supply of development rights: results from a survey in Hadley, Massachusetts. Land Economics 55, 269-276.

Cramton, P., Ausubel, L. M., 2002. Demand reduction and inefficiency in multi-unit auctions. Working Paper, University of Maryland.

D'Aquino, P., Le Page, C., Bousquet, F., Bah, A., 2003. Using self-designed role-playing games and a multi-agent system to empower a local decision-making process for land use management: the Self Cormas experiment in Senegal. Journal of Artificial Societies and Social Simulation 6(3), 5.

De Kam, G., Lubach, D., 2007. Tradable building rights and the financing of urban renewal. Town Planning Review 78, 103-118.

Deadman, P., Robinson, D., Moran, E., Brondizio, E., 2004. Colonist household decision making and land use change in the Amazon Rainforest: An agent-based simulation. Environment and Planning B: Planning and Design 31, 693-709.

Dillman, D.A., Smith, J.D., Christian, L.M., 2009. Internet, mail, and mixed-mode surveys: the tailored design method. Third Edition. John Wiley & Sons Inc., Hoboken, NJ, USA.

Duffy, J., 2006. Agent-based models and human subject experiments. In: Tesfatsion, L., Kenneth, L. J. (Eds), Handbook of Computational Economics. Elsevier, B. V., Amsterdam, pp 950-1005.

Dürr, B., Zelenka, A., Müller, R., Philipona, R., 2010. Verification of CM-SAF and MeteoSwiss satellite based retrievals of surface shortwave irradiance over the alpine region. International Journal of Remote Sensing 31, 4179- 4198.

EEA, European Environment Agency, 2006. Urban sprawl in Europe. Report No 10/2006 by the European Environment Agency. http://reports.eea.europa.eu/eea_report_2006_10/en/eea_report_10_2006.pdf (accessed: 2012-05-16).

Epiney, A., 2003. Marktwirtschaftliche Instrumente in der Raumplanung - ein Problemaufriss aus rechtlicher Sicht. Internes Arbeitspapier zum ARE-Workshop "Marktwirtschaftliche Instrumente in der Raumplanung", Institut für Europarecht Universität Freiburg, Freiburg.

Evans and Peck, 2007. National Emissions Trading Taskforce: Possible Design for a Greenhouse Gas Emissions Trading System - Further Definition of the Auction Proposals in the NETT Discussion Paper. National Emissions Trading Taskforce, Sydney.

Ewing, R.H., 2008. Characteristics, causes, and effects of sprawl: a literature review. Urban Ecology Section V, 519-535.

Fahrländer Partner AG, 2008. Bauzonen Schweiz: Wie viele Bauzonen braucht die Schweiz? Zürich.

Feola, G., Gallati, J.A., Binder, C.R., 2011. Exploring behavioural change through an agent-oriented system dynamics model: the use of personal protective equipment among pesticide applicators in Colombia. System Dynamics Review 28 (1), 69-93.

Filatova, T., Parker, D., van der Veen, A., 2009. Agent-based urban land markets: agent's pricing behavior, land prices and urban land use change. Journal of Artificial Societies and Social Simulation 12(1), 3.

Fudenberg, D., Tirole, J., 1991. Game Theory. The MIT Press.

Gerheuser, F.W., 2004. Eidgenössische Volkszählung 2000, Wohnversorgung und Wohnverhältnisse, Entwicklungen 1990-2000. Swiss Federal Statistical Office SFSO, Neuchâtel.

Gibson, D.J., 1996. Planning A Market: Transferable Planning Mechanisms in New Zealand. Massey University.

Gilbert, N., 2007. Agent-based Models. SAGE Publications, London.

Gmünder, M., 2004. Mit weniger Planung zu mehr Raum? Zum Einsatz anreizorientierter Instrumente in der Raumplanung. In: Schaltegger, C.A. Schaltegger, S.C. (Eds.), Perspektiven der Wirtschaftspolitik. Vdf, Zürich.

Gmünder, M., 2010. Raumplanung zwischen Regulierung und Markt. Eine ökonomische Analyse anreizorientierter Instrumente in der Raumplanung. Rüegger Verlag, Zürich, Chur.

Gode, D., Sunder, S., 1993. Allocative efficiency of markets with zero-intelligence traders: Market as a partial substitute for individual rationality. The Journal of Political Economy 101, 119-137.

Häder, M., 2010. Empirische Sozialforschung. Eine Einführung. VS Verlag, Wiesbaden.

Häfelin, U., Müller, G., Uhlmann, F., 2010. Allgemeines Verwaltungsrecht. 6. vollständig überarbeitete Auflage. Dike, Zürich.

Hamby, D.M., 1994. A review of techniques for parameter sensitivity analysis of environmental models. Environmental Monitoring and Assessment 32, 135-154.

Happe, K., Kellermann, K., Balmann, A., 2006. Agent-based analysis of agricultural policies: an illustration of the agricultural policy simulator AgriPoliS, its adaptation and behavior. Ecology and Society 11(1), http://www.ecologyandsociety.org/vol11/iss1/art49 (accessed: 2012-08-23).

Henger, R., Bizer, K., 2010. Tradable planning permits for land-use control in Germany. Land Use Policy 27, 843-852.

Huang, P., Scheller-Wolf, A., Sycara, K., 2002. Design of a multi-unit double auction e-market. Computational Intelligence 18(4), 596-617.

Hurtubia, R.D., 2012. Discrete choice and microsimulation methods for agent-based land use modeling. Thèse EPFL, no 5554 (2012), Lausanne.

IRL, Institut für Raum- und Landschaftsentwicklung (Ed.), 2003. Siedlungsentwicklung Schweiz, Analyse auf der Grundlage der Arealstatistik 1979/85 und 1992/97, Entwicklung – Situation - Trends, Werkstattbericht. ETH Zürich.

Jamison, J.C., Plott, C.R., 1997. Costly offers and the equilibration properties of the multiple unit double auction under conditions of unpredictable shifts of demand and supply. Journal of Economic Behavior & Organization 32, 591-612.

Janssen, M.A., Ostrom, E., 2006. Empirically based, agent-based models. Ecology and Society 11 (2), 37. http://www.ecologyandsociety.org/vol11/iss2/art37 (accessed: 2012-08-13).

Janssen-Jansen, L., Spaans, M., van der Veen, M., 2008. New instruments in spatial planning, an international perspective on non-financial compensation. Sustainable Urban Areas. IOS Press, Delft and Amsterdam (NL).

Johnston, R.A., Madison, M.E., 1997. From landmarks to landscapes: A review of current practices in the transfer of development rights. Journal of American Planning Association 63, 365-379.

Kanton Zürich, 2007. Raumbeobachtung Kanton Zürich, Siedlungsentwicklung, Heft 25. Zürich.

Kanton Zürich, 2009. Raumplanungsbericht 2009. Zürich.

Kaplowitz, M.D., Machemer, P., Pruetz, R., 2008. Planners' experiences in managing growth using transferable development rights (TDR) in the United States. Land Use Policy, 25, 378-387.

Kaufmann-Hayoz, R., Gutscher, H. (Ed.), 2001. Changing things – moving people: strategies for promoting sustainable development at the local level. Birkhäuser Verlag: Basel, Boston, Berlin.

Kaufmann, P., Rieder, T., 2012. Zweitwohnungsbaustopp: Mögliche Auswirkungen auf die Immobilienpreise in den Tourismusregionen. Die Volkswirtschaft, Das Magazin für Wirtschaftspolitik 6, 63-66.

Kaufmann, P., Stagl, S., Franks, D.W., 2009. Simulating the diffusion of organic farming practices in two New EU Member States. Ecological Economics 68, 2580–2593.

Klemperer, P., 2004. Auctions: Theory and Practice. Princeton University Press, Princeton.

Klügl, F., 2008. A Validation Methodology for Agent-based Simulations. In: Proceedings of the 2008 ACM Symposium on Applied Computing, 39-43. SAC '08. ACM, 2008, New York, NY, USA.

Kopits, E., McConnel, V., Walls, M., 2005. Making markets for development rights work. What determines demand? Land Economics 84(1), 1-16.

Krishna, V., 2002. Auction Theory. Academic Press, London.

LeBaron, B., 2006. Agent-based computational finance (Chapter 24). In: Tesfatsion, L., Judd, K. L. (Eds.), Handbook of computational economics: Agent-based computational economics. Elsevier, Amsterdam, pp. 1187-1233.

Lesschen, J., Verburg, P., Staal, S., 2005. Statistical Methods for Analyzing the Spatial Dimension of Changes in Land Use and Farming Systems. LUCC Report Series 7. Wageningen University, Wageningen (NL).

Louie M.A., Carley K.M., 2008. Balancing the criticisms: validating multi-agent models of social systems. Simulation Modelling Practice and Theory 16, 242-256.

Machemer, P.L., Kaplowitz, M.D., 2002. A Framework for evaluating transferable development rights programmes. Journal of Environmental Planning and Management 45, 773-795.

Magliocca, N.R., Safirova, E., McConnell, V., Walls, M., 2011. An economic agent-based model of coupled housing and land markets (CHALMS). Computers, Environment, and Urban Systems 35 (3), 183-191.

Mann, J.K., Barber, G.R., 2007. Bundle of rights approach to value. Article written as a service to the Private Landowner Network. Barber and Mann, Inc., Rideland, MS, USA.

Marks, R., 2006. Market design using agent-based models. In: Tesfatsion, L., Judd, K.L. (Eds.), Handbook of computational economics: Agent-based computational economics. Elsevier, Amsterdam, pp. 1339-1380.

Matthews, R.B., Gilbert, N.G., Roach, A., Polhill, J.G., Gotts, N.M., 2007. Agent-based land-use models: a review of applications. Landscape Ecology 22, 1447-1459.

McAfee, R.P., McMillan, J., 1987. Auctions and bidding. Journal of Economic Literature 25, 699-738.

Micelli, E., 2002. Development rights markets to manage urban plans in italy. Urban Studies 39, 141-154.

Mitchell, R.C., Carson, R.T., 1993. Using surveys to value public goods: the contingent valuation method. Resources for the Future, Washington, D.C.

Myerson, R., Satterthwaite, M., 1983. Efficient mechanisms for bilateral trading. Journal of Economic Theory 28, 265-281.

North, M. J., Macal, C.M., 2007. Managing Business Complexity: Discovering Strategic Solutions with Agent-Based Modeling and Simulation. Oxford University Press, Oxford.

Noussair, C., Robin, S., Ruffieux, B., 1998. The effect of transaction costs on double auction markets. Journal of Economic Behavior & Organization 36, 221-233.

NZZ (Neue Zürcher Zeitung), 2012. Detroit in den Alpen? NZZ, 08.06.2012. http://www.nzz.ch/aktuell/schweiz/detroit-in-den-alpen-1.17211049 (accessed: 2012-12-14).

NZZ (Neue Zürcher Zeitung), 2007a. Den knappen Boden in der Schweiz besser nutzen. NZZ, 07. August 2007. http://www.nzz.ch/aktuell/startseite/hauseigentuemerverband-raumplanung-forderungen - 1.537691 (accessed: 2012-12-14) .

NZZ (Neue Zürcher Zeitung), 2007b. Die Zersiedlung der Schweiz im Visier. NZZ, 26. July 2007. http://www.nzz.ch/aktuell/startseite/die-zersiedlung-der-schweiz-im-visier-1.532736 (accessed: 2012-12-14) .

Oreskes N., Shrader-Frechette K., Belitz K., 1994. Verification, validation, and confirmation of numerical models in the earth sciences. Science 263, 641-646.

Parker, D.C., Berger, T., Manson, S., 2002. Agent-based models of land use and land-cover change. Report and Review of an International Workshop. Anthropological Center for Training and Research on Global Environmental Change, Irvine, CA, USA, Indiana University, Bloomington, IN, USA.

Parker, D.C., Filatova, T., 2008. A conceptual design for a bilateral agent-based land market with heterogeneous economic agents. Computers, Environment and Urban Systems 32, 454-463.

Parker, D.C., Meretsky, V., 2004. Measuring pattern outcomes in an agent-based model of edge-effect externalities using spatial metrics. Agriculture, Ecosystems and Environment 101, 233-250.

Polhill, J.G., Gotts, N.M., Law, A.N.R., 2001. Imitative versus nonimitative strategies in a land use simulation. Cybernetics and Systems: An International Journal 32, 285-307.

Polhill, J.G., Parker, D., Gotts, N.M., 2008. Effects of land markets on competition between innovators and imitators in land use: results from FEARLUS-ELMM. In: Hernandez, C., Troitzsch, K., Edmonds, B. (Eds.), Social Simulation Technologies: Advances and New Discoveries. IGI Global, Hershey, pp. 81-97.

Pruetz, R., 2003. Beyond Takings and Givings. Arje Press, Marina Del Rey, California.

Radcliffe, Robert C., 1997. Investment: Concepts, Analysis, Strategy. Addison-Wesley Educational Publishers, Chicago.

Radermacher, F.J., Renn, O., Kaule, G., Zeddies, J., Höpfner, U., 2004. Neue Wege zu einem nachhaltigen Flächenmanagement in Baden-Württemberg. Sondergutachten. Der Nachhaltigkeitsrat der Landesregierung Baden-Württemberg, Baden-Württemberg, Stuttgart.

Renard, V., 1999. Application of Tradable Permits to Land-Use Management. In: OECD (Ed.), Implementing Domestic Tradable Permits for Environmental Protection. OECD, Paris, pp. 53-73.

Robinson, D.T., Brown, D.G., 2009. Evaluating the effects of land-use development policies on ex-urban forest cover: An integrated agent-based GIS approach. International Journal of Geographical Information Science 23 (9), 1211-1232.

Schläpfer, F., 2007. Marktwirtschaftliche Instrumente in der Raumplanung. GAIA 16, 178-180.

Schutte S., 2010. Optimization and Falsification in Empirical Agent-Based Models. Journal of Artificial Societies and Social Simulation 13 (1), http://jasss.soc.surrey.ac.uk/13/1/2.html (accessed: 2012-12-13).

Schwarz, N., Ernst, A., 2009. Agent-based modeling of the diffusion of environmental innovations - an empirical approach. Technological Forecasting & Social Change 76, 497–511.

Seidl, I., Schultz, B., Gellrich, M., 2009. Flächenzertifikate. Ein Instrument zur Senkung der Flächeninanspruchnahme? Wissenschaft und Umwelt 12, 150-156.

SFSO, 2010a. Swiss Land Use Statistics (Arealstatistik). Swiss Federal Statistical Office SFSO, Neuchâtel.

SFSO, 2010b. BFS Aktuell, Landschaft Schweiz im Wandel, Raum und Umwelt, 2, Swiss Federal Statistical Office SFSO, Neuchâtel.

SFSO, 2010c. Scenarios on population growth in Switzerland 2010-2060. Swiss Federal Statistical Office SFSO, Neuchâtel.

Skiera, B., Revenstorff, I., 1999. Auktionen als Instrument zur Erhebung von Zahlungsbereitschaften. Schmalenbachs Zeitschrift für betriebswirtschaftliche Forschung 51, 224-242.

Süess, A., Gmünder, M., 2005. Weniger Zersiedelung durch handelbare Flächennutzungszertifikate? DISP 160, 58-66.

Tan, R., Beckmann, V., 2010. Diversity of practical quota systems for farmland preservation: A multicountry comparison and analysis. Environment and Planning C: Government and Policy 28, 211-224.

Torrens, P.M., 2010. Agent-based Models and the Spatial Sciences. Geography Compass 4(5), 428-448.

Vickrey, W., 1961. Counterspeculation, auctions, and competitive sealed tenders. Journal of Finance 16, 8-37.

VLP-ASPAN, Swiss Planning Association, 2011. Rechtsprechung des Bundesgerichts 2010. Raum und Umwelt, März Nr. 2/11.

VLP-ASPAN, Swiss Planning Association, 2012. Rechtsprechung des Bundesgerichts 2011. Raum und Umwelt, März Nr. 2/12.

VLP-ASPAN, Swiss Planning Association, n.s.. Spatial planning in Switzerland: a short introduction. Bern.

Wüest und Partner AG, 2011. Grundstücksdaten EFH/MFH und Baulandpreise. Zürich. http://www.wuestundpartner.com/online_services/baulandpreise/index_e.phtml (accessed: 2012 -12-14).

Wüest und Partner AG, 2012. Immo-Monitoring. Verlag W&P, Wüest & Partner AG, Zürich.

Zollinger, F., 2006. Potenzial und Grenzen handelbarer Flächennutzungszertifikate in der Schweiz. GAIA 15, 184.

Zollinger, F., Seidl, I., 2005. Flächenzertifikate für eine nachhaltige Raumentwicklung? Ein Konzept für Baden-Württemberg und Erkenntnisse aus der Übertragung auf die Schweiz. Information zur Raumentwicklung, Heft 4/5, 273-280.

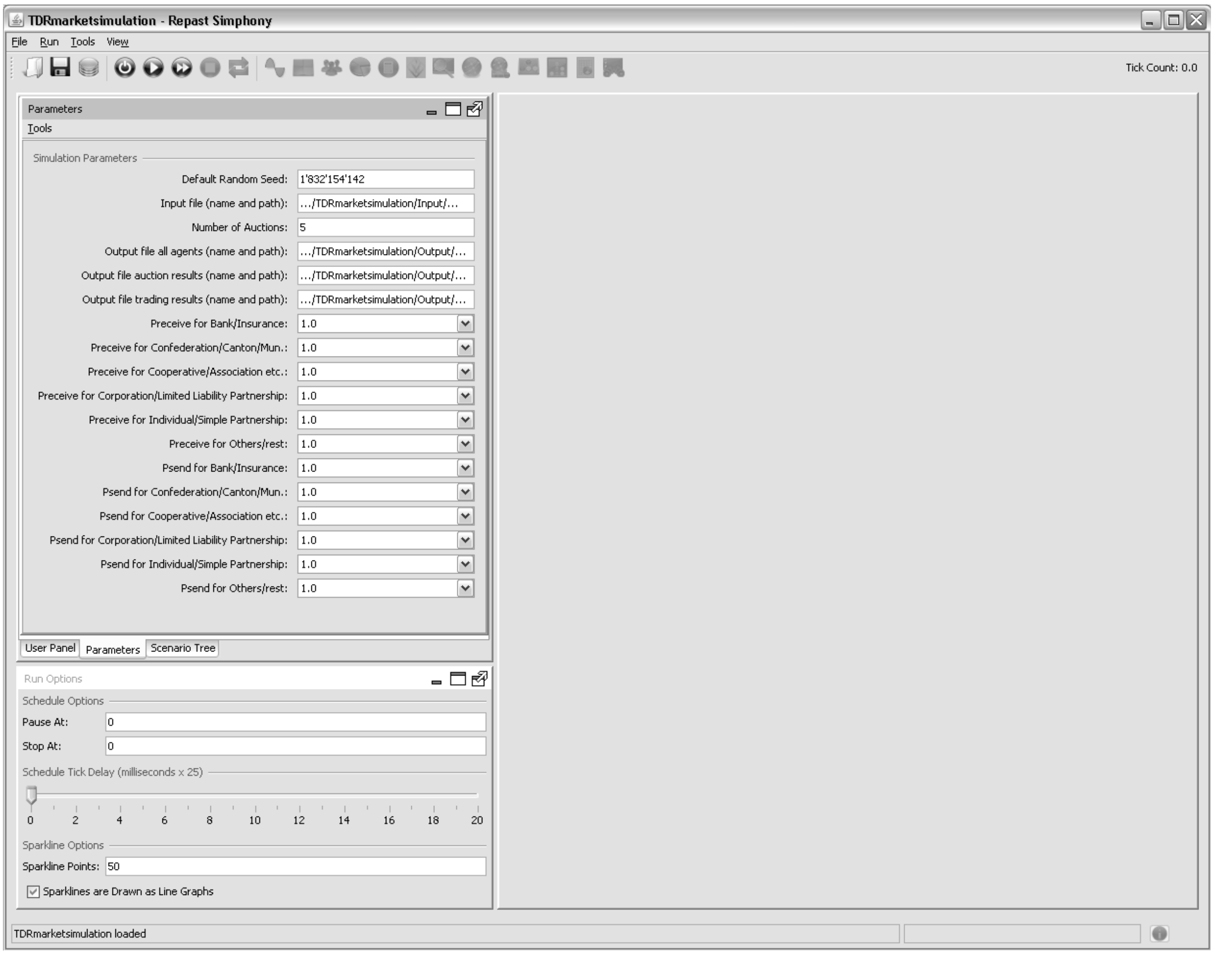
A Appendix to Chapter 2

A.1 Example of input data

Table A-1: Example of input data.

Parcel-ID	Agent type	Landowner category	Parcel area (sqm)	Agricultural zone price (CHF/sqm)	Building zone price (CHF/sqm)	Utilization factor
1	S	A	427	6	300	0.4
2	S	B	628	5	250	0.3
3	R	B	500	5	860	0.7
4	R	C	325	4	1,050	0.4
…	…	…	…	…	…	…

A.2 Screenshot Repast Environment



Simulation Parameters

Default Random Seed: 1'832'154'142

Input file (name and path): .../TDRmarketsimulation/Input/...

Number of Auctions: 5

Output file all agents (name and path): .../TDRmarketsimulation/Output/...

Output file auction results (name and path): .../TDRmarketsimulation/Output/...

Output file trading results (name and path): .../TDRmarketsimulation/Output/...

Preceive for Bank/Insurance: 1.0

Preceive for Confederation/Canton/Mun.: 1.0

Preceive for Cooperative/Association etc.: 1.0

Preceive for Corporation/Limited Liability Partnership: 1.0

Preceive for Individual/Simple Partnership: 1.0

Preceive for Others/rest: 1.0

Psend for Bank/Insurance: 1.0

Psend for Confederation/Canton/Mun.: 1.0

Psend for Cooperative/Association etc.: 1.0

Psend for Corporation/Limited Liability Partnership: 1.0

Psend for Individual/Simple Partnership: 1.0

Psend for Others/rest: 1.0

Schedule Options

Pause At: 0

Stop At: 0

Schedule Tick Delay (milliseconds x 25): 0

Sparkline Options

Sparkline Points: 50

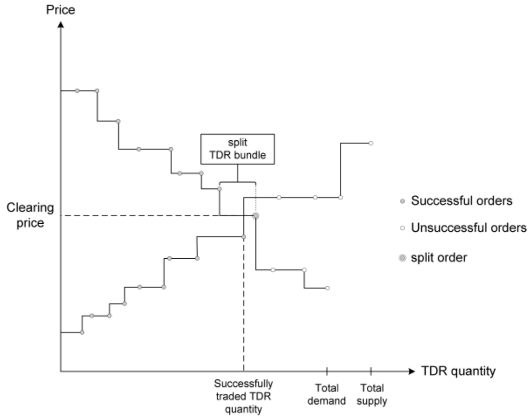
☑ Sparklines are Drawn as Line Graphs

TDRmarketsimulation loaded

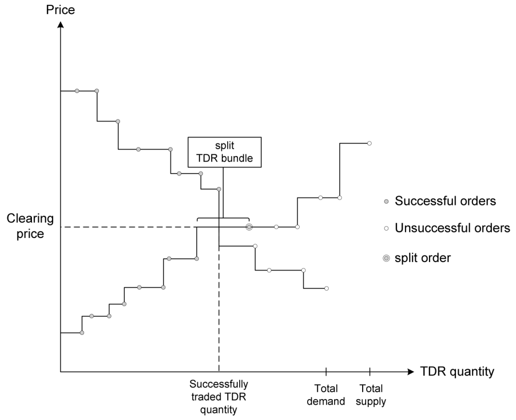
Fig. A-1: Screenshot Repast Environment.

A.3 Special cases in the calculation of the clearing price

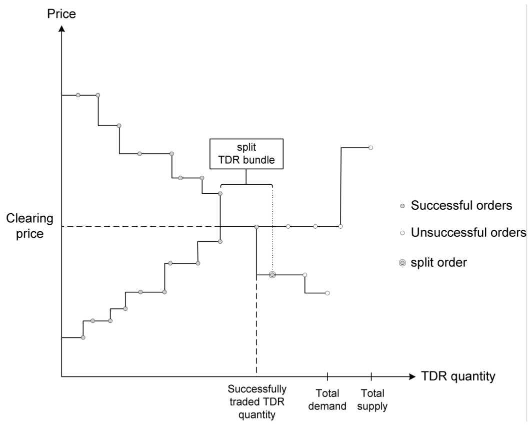
TDR bundle of last successful receiver is split



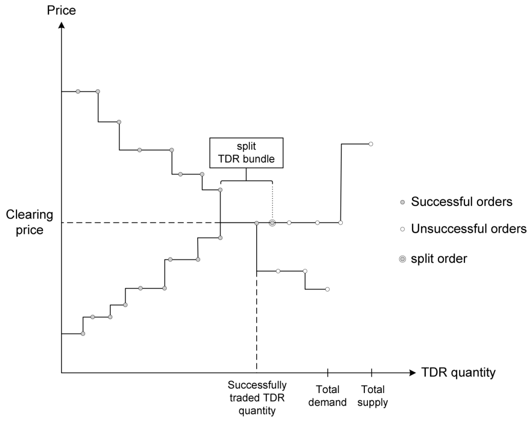
TDR bundle of last successful sender is split



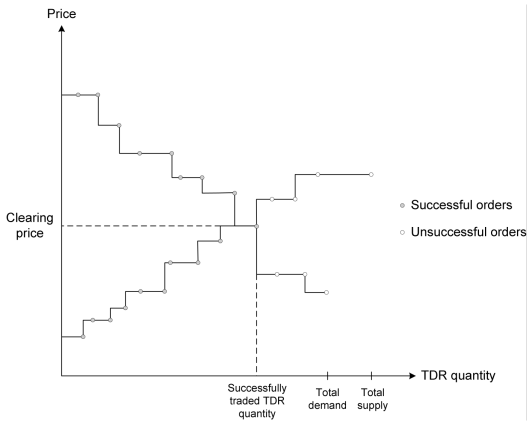
Equal prices at intersection, TDR bundle of last successful receiver is split



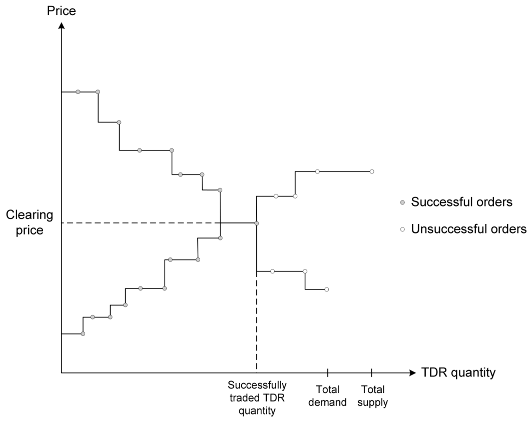
Equal price at intersection, TDR bundle of last successful sender is split



Equal price and TDR quantity at intersection (v.1)



Equal price and TDR quantity at intersection (v.2)



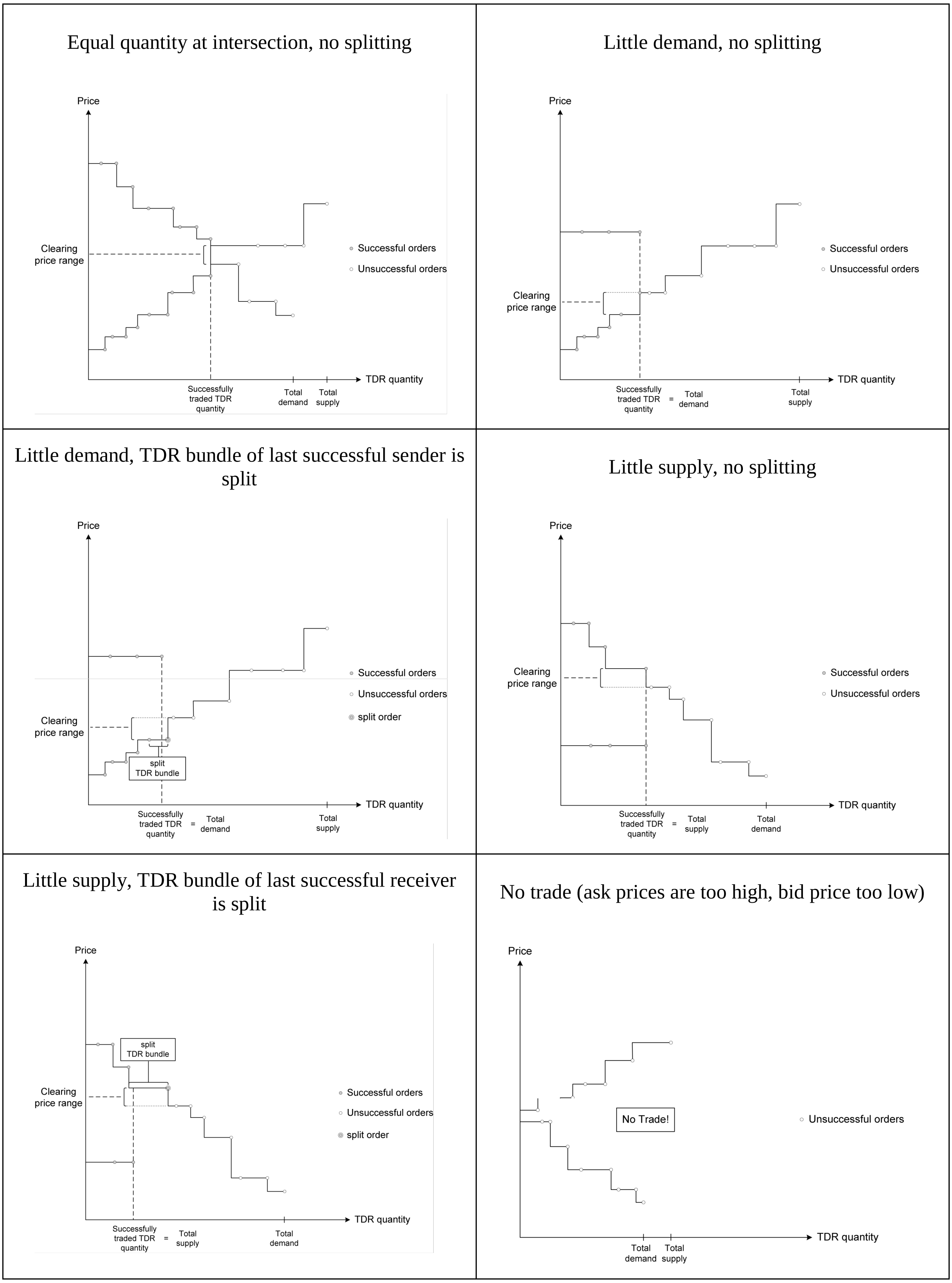
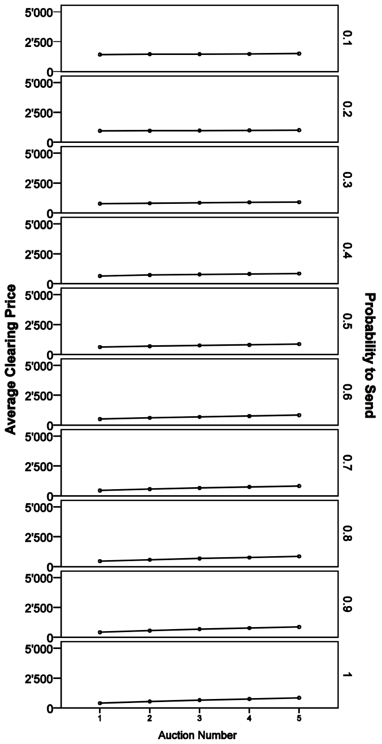
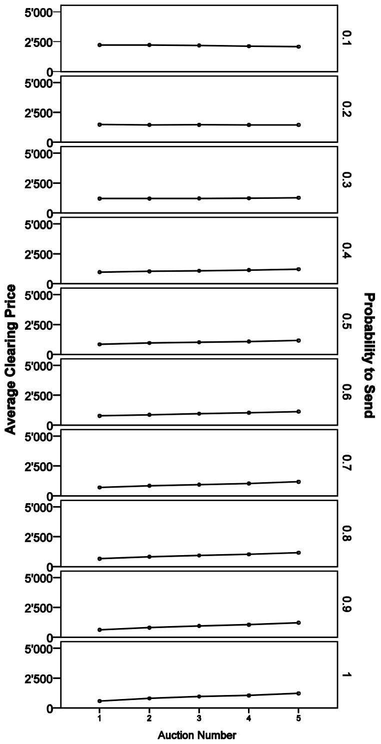
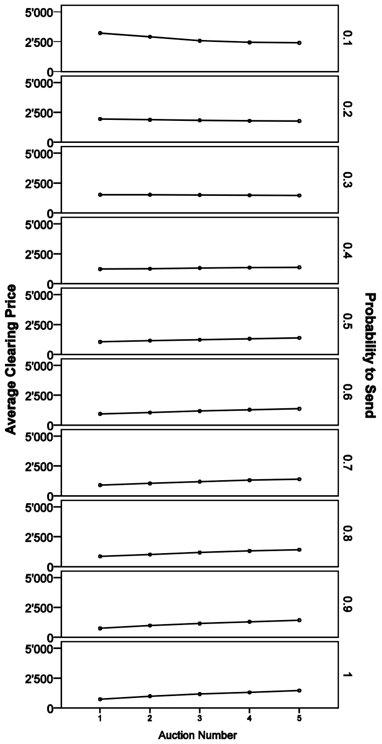
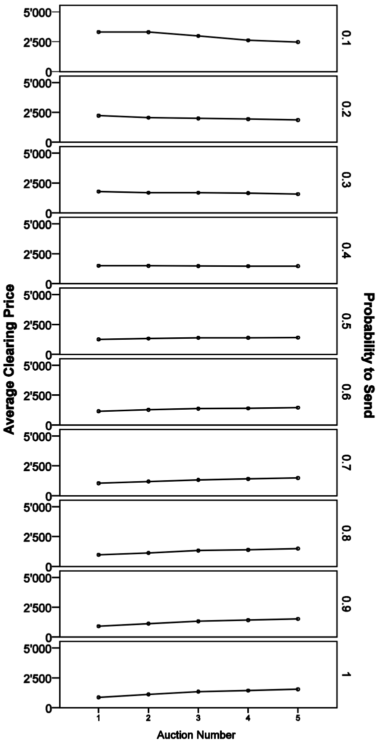
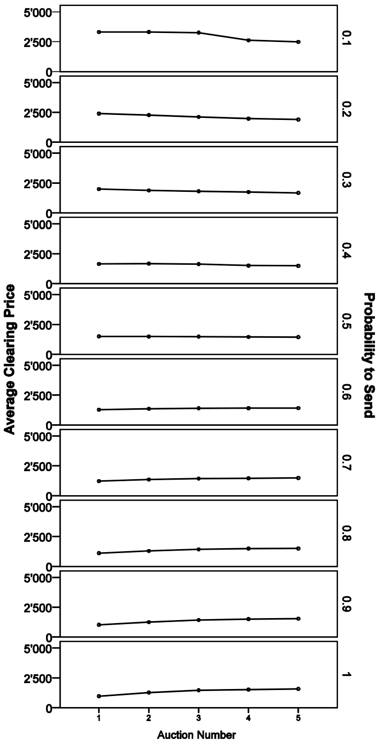
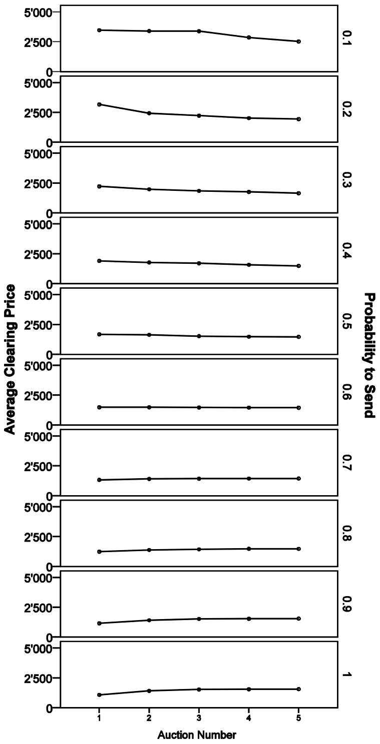
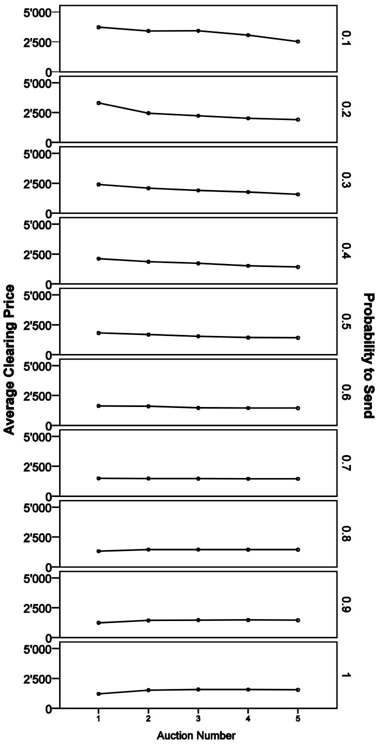
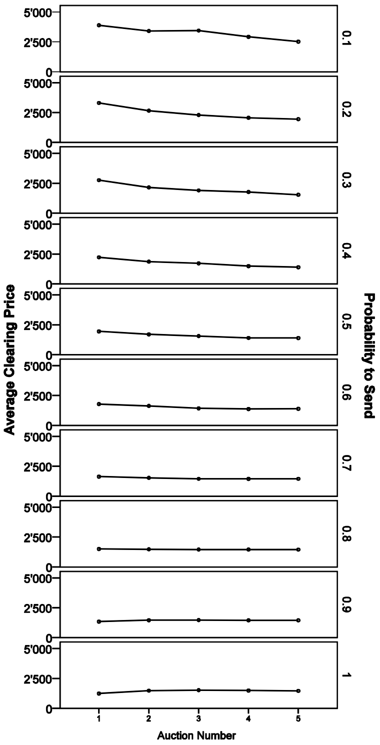
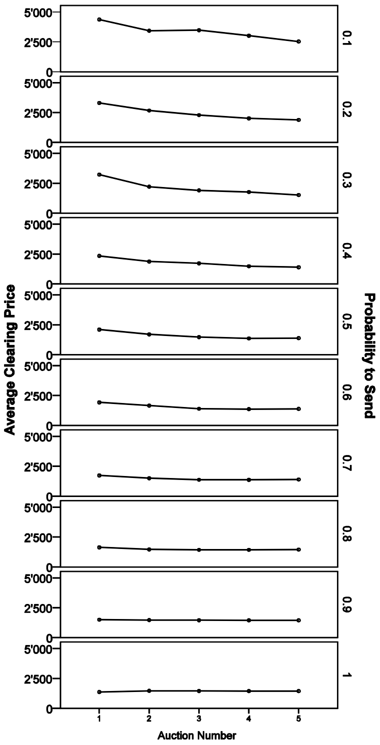


Fig. A-2: Special cases in the calculation of the market clearing price.

A.4 Effect of different p_{send} and $p_{receive}$ values on the clearing price over 5 auctions

p_{send} changes; $p_{receive}$ constant at *10%*	p_{send} changes; $p_{receive}$ constant at *20%*	p_{send} changes; $p_{receive}$ constant at *30%*
		

p_{send} changes; $p_{receive}$ constant at *40%*	p_{send} changes; $p_{receive}$ constant at *50%*	p_{send} changes; $p_{receive}$ constant at *60%*
		

p_{send} changes; $p_{receive}$ constant at *70%*	p_{send} changes; $p_{receive}$ constant at *80%*	p_{send} changes; $p_{receive}$ constant at *90%*
		

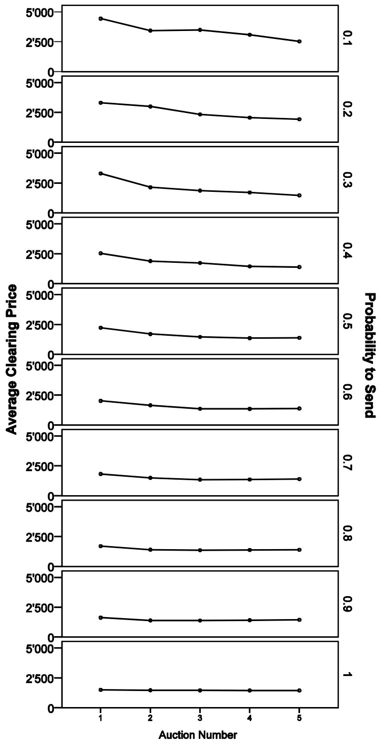
p_{send} changes; $p_{receive}$ constant at *100%*	
	

Fig. A-3: Effect of different p_{send} and $p_{receive}$ values on the clearing price over 5 auctions.

B Appendix to Chapter 3

B.1 Histograms for plausibility test

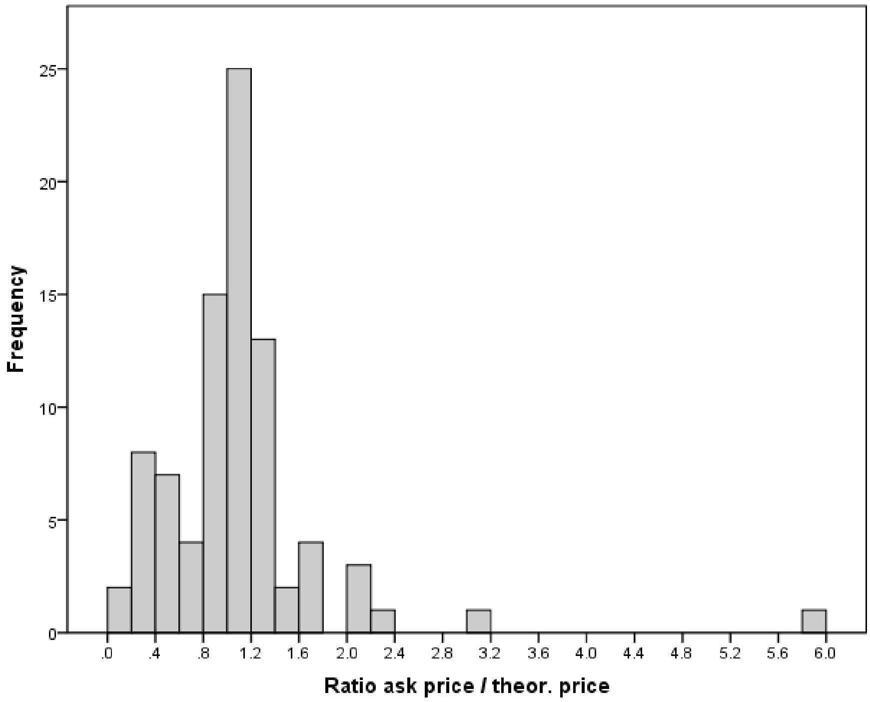


Fig. B-1: Histogram of the ratio of first ask price and theoretical price.

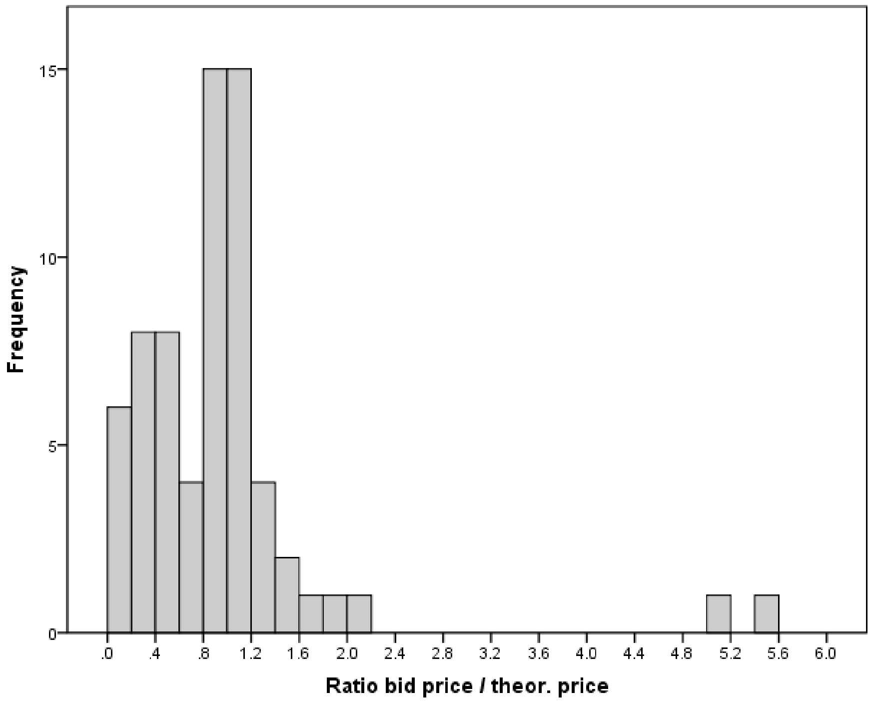


Fig. B-2: Histogram of the ratio of fifth bid price and theoretical price.

B.2 Participation probability per landowner category before exclusion of outliers

Table B-1: Sender and receiver participation probability per landowner category before exclusion of outliers.

Landowner category		**Sender Participation**		**Receiver Participation**	
		Yes	**No**	**Yes**	**No**
Enterprises	Number	18	17	14	12
	Percent	51.4%	48.6%	53.8%	46.2%
NPI	Number	23	43	14	50
	Percent	34.8%	65.2%	21.9%	78.1%
RPP	Number	50	30	40	20
	Percent	62.5%	37.5%	66.7%	33.3%
Overall	Number	91	90	68	82
	Percent	50.3%	49.7%	45.3%	54.7%

B.3 Regression models for testing the influence of the location factor

Sender

Table B-2: Determinants (model with location factor) of first ask price of enterprises (MOD SE 2)[a].

	MOD SE 2			
Variable name	Coefficients	t-values	Lower level of 95% confidence interval	Upper level of 95% confidence interval
Constant	2,612.353*	2.232	-34.789	5,259.495
ParcelArea	-1.975**	-2.708	-3.625	-0.325
$PTDR_{theoretical}$	1.048	1.353	-0.704	2.799
AdaptationRate	-275.123	-0.295	-2,385.321	1,835.074
Number of observations	15			
R^2	0.493			
Adjusted R^2	0.324			

[a] Significance levels (two-tailed): *** 1%, ** 5%, * 10%.

Table B-3: Determinants (model with location factor) of first ask price of NPI (MOD SNPI 2)[a].

	MOD SNPI 2			
Variable name	Coefficients	t-values	Lower level of 95% confidence interval	Upper level of 95% confidence interval
Constant	1,139.818	1.602	-396.910	2,676.547
ParcelArea	-0.771	1.191	-2.169	0.628
$PTDR_{theoretical}$	1.000***	3.236	0.332	1.668
AdaptationRate	-378.593	-0.673	-1,594.704	837.517
Number of observations	18			
R^2	0.487			
Adjusted R^2	0.368			

[a] Significance levels (two-tailed): *** 1%, ** 5%, * 10%.

Table B-4: Determinants (model with location factor) of first ask price of RPP (MOD SRPP 2)[a].

	MOD SRPP 2			
Variable name	Coefficients	t-values	Lower level of 95% confidence interval	Upper level of 95% confidence interval
Constant	135.295	0.732	-241.851	512.441
ParcelArea	0.120	0.701	-0.229	0.469
$PTDR_{theoretical}$	0.947^{***}	10.072	0.755	1.139
AdaptationRate	-199.188	-0.929	-636.713	238.337
Number of observations	38			
R^2	0.777			
Adjusted R^2	0.755			

[a] Significance levels (two-tailed): *** 1%, ** 5%, * 10%.

Receiver

Table B-5: Determinants (model with location factor) of first bid price of enterprises (MOD RE 2)[a].

	MOD RE 2			
Variable name	Coefficients	t-values	Lower level of 95% confidence interval	Upper level of 95% confidence interval
Constant	1,657.015	1.604	-725.833	4,039.863
ParcelArea	-.0965	-1.268	-2.720	0.790
$PTDR_{theoretical}$	0.503	1.325	-0.373	1.379
AdaptationRate	-288.811	-1.120	-883.622	306.000
Number of observations	12			
R^2	0.492			
Adjusted R^2	0.242			

[a] Significance levels (two-tailed): *** 1%, ** 5%, * 10%.

Table B-6: Determinants (model with location factor) of first bid price of NPI (MOD RNPI 2)[a].

	MOD RNPI 2			
Variable name	Coefficients	t-values	Lower level of 95% confidence interval	Upper level of 95% confidence interval
Constant	325.527	1.068	-458.267	1,109.321
ParcelArea	0.495	1.669	-0.267	1.258
$PTDR_{theoretical}$	0.219^{***}	4.574	0.096	0.342
AdaptationRate	-674.622^{**}	-2.994	-1,253.772	-95.472
Number of observations	10			
R^2	0.916			
Adjusted R^2	0.865			

[a] Significance levels (two-tailed): *** 1%, ** 5%, * 10%.

Table B-7: Determinants (model with location factor) of first bid price of RPP (MOD RRPP 3)[a].

	MOD RRPP 3			
Variable name	Coefficients	t-values	Lower level of 95% confidence interval	Upper level of 95% confidence interval
Constant	402.555	1.257	-255.577	1,060.688
ParcelArea	-0.129	-0.467	-0.696	0.439
$PTDR_{theoretical}$	0.629^{***}	4.020	0.307	0.951
AdaptationRate	-265.835^{***}	-2.760	-463.799	-67.870
Number of observations	31			
R^2	0.547			
Adjusted R^2	0.495			

[a] Significance levels (two-tailed): *** 1%, ** 5%, * 10%.

B.4 Ask and bid price adaptation per landowner category

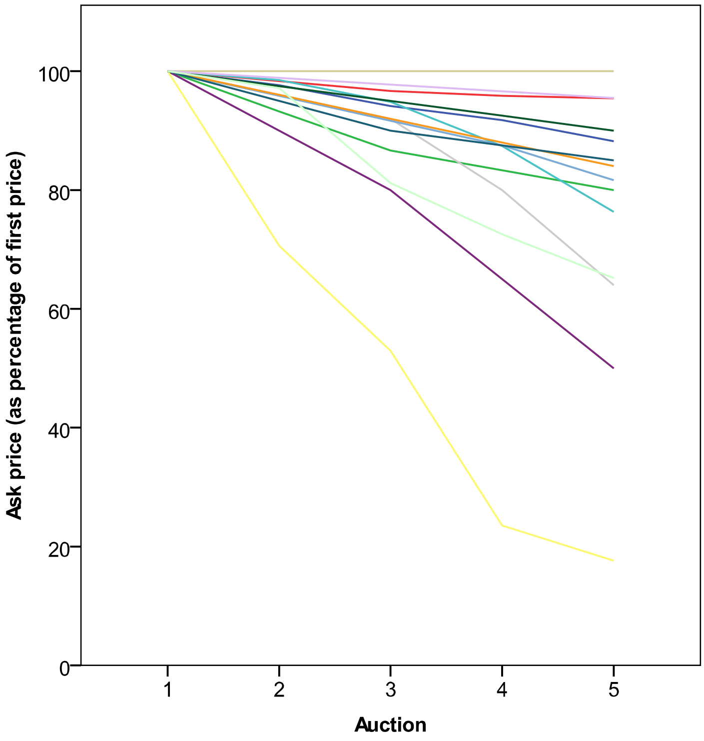


Fig. B-3: Ask price adaptation of senders of the category of enterprises.

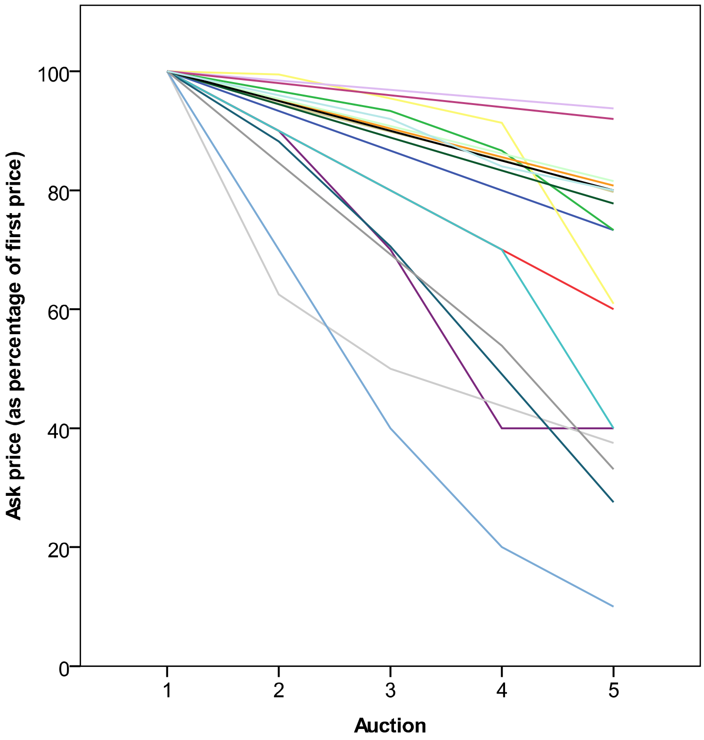


Fig. B-4: Ask price adaptation of senders of the category of NPI.

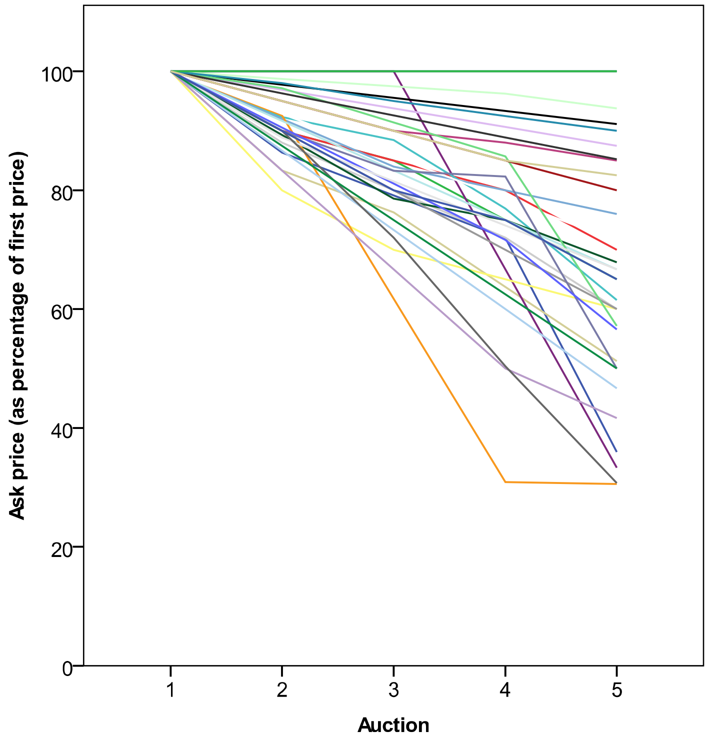


Fig. B-5: Ask price adaptation of senders of the category of RPP.

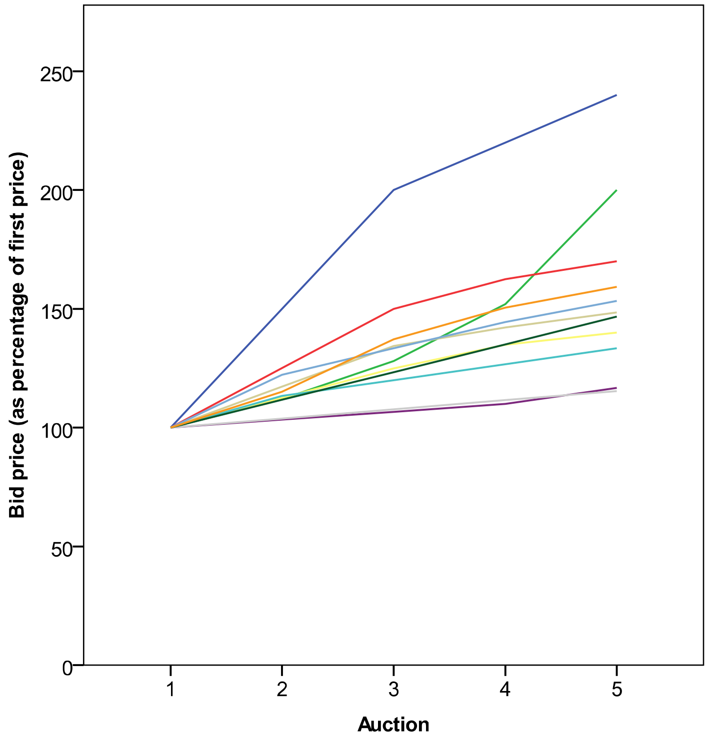


Fig. B-6: Bid price adaptation of receivers of the category of enterprises.

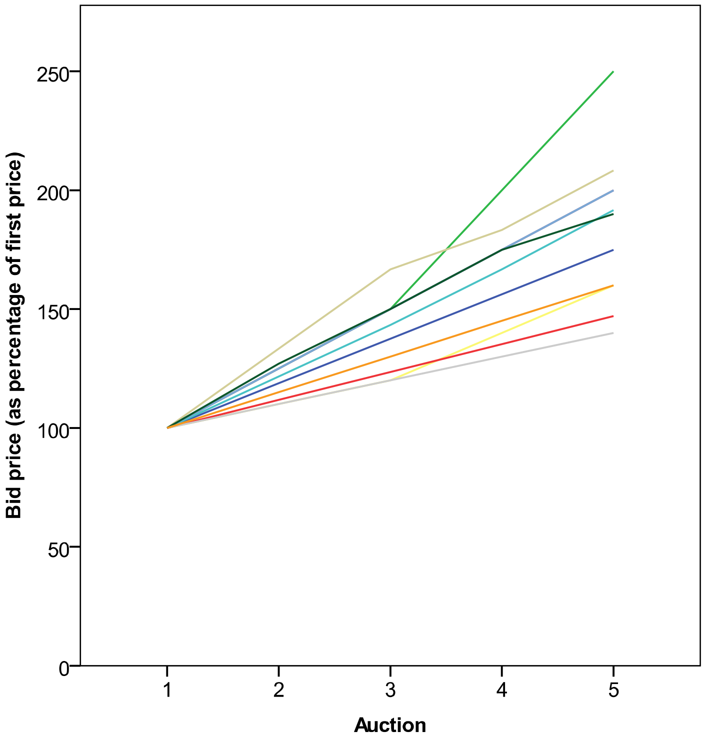


Fig. B-7: Bid price adaptation of receivers of the category of NPI.

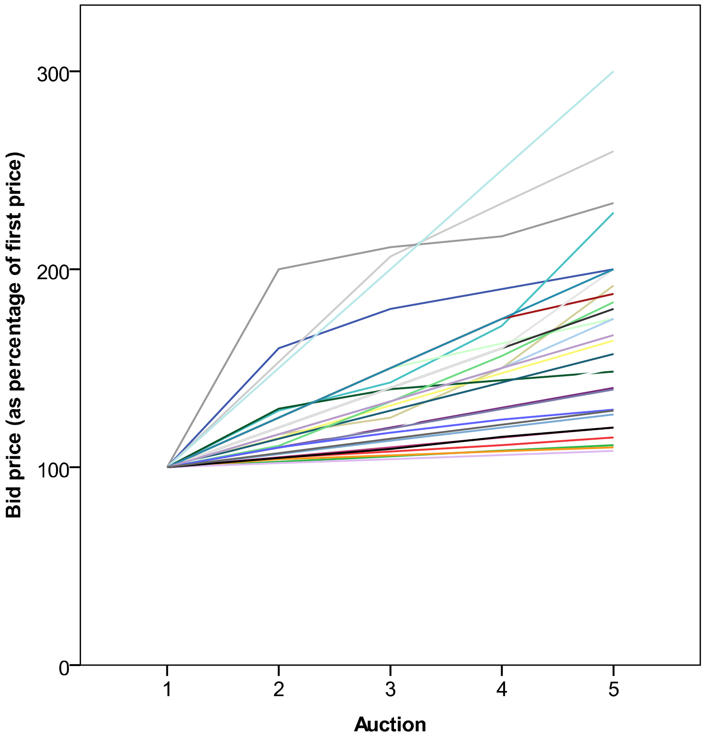


Fig. B-8: Bid price adaptation of receivers of the category of RPP.

C Appendix to Chapter 4

C.1 Characteristics of the sending and receiving area

Table C-1: Characteristics (municipality type level) of the sending and receiving areas for the year 2018 (own calculations, data basis: ARE, 2008 and Fahrländer Partner, 2008).

Municipality type[118]	**Sending area**		**Receiving area**	
	Area (in km2)	**Assigned TDR quantity**	**Area (in km2)**	**Assigned TDR quantity**
Large cities (Basle, Berne, Geneva, Lausanne, Zurich)	0.00	0	3.09	2,335,194
Medium-sized cities (e.g. Winterthur, Olten)	1.13	564,034	1.07	603,919
Small cities (e.g. Lenzburg, Herisau)	1.70	574,068	1.17	444,961
Rich municipalities (e.g. Cologny, Wollerau)	1.15	314,576	2.01	671,519
Tourist municipalities (e.g. Flims, Saas-Fee)	6.32	1,576,527	0.25	95,146
Inner agglomeration belt of large cities (e.g. Gland, Horgen)	2.41	860,391	6.03	2,491,414
Outer agglomeration belt of large cities (e.g. Bonstetten, Coldrerio)	1.98	606,051	2.69	987,389
Inner agglomeration belt of medium-sized cities (e.g. Amriswil, Horn)	2.21	741,939	1.18	440,013
Outer agglomeration belt of medium-sized cities (e.g. Felsberg, Magliaso)	3.22	828,616	0.54	193,569
Commuter municipalities outside agglomerations (e.g. Adlikon, Vinelz)	3.30	869,935	1.58	490,053

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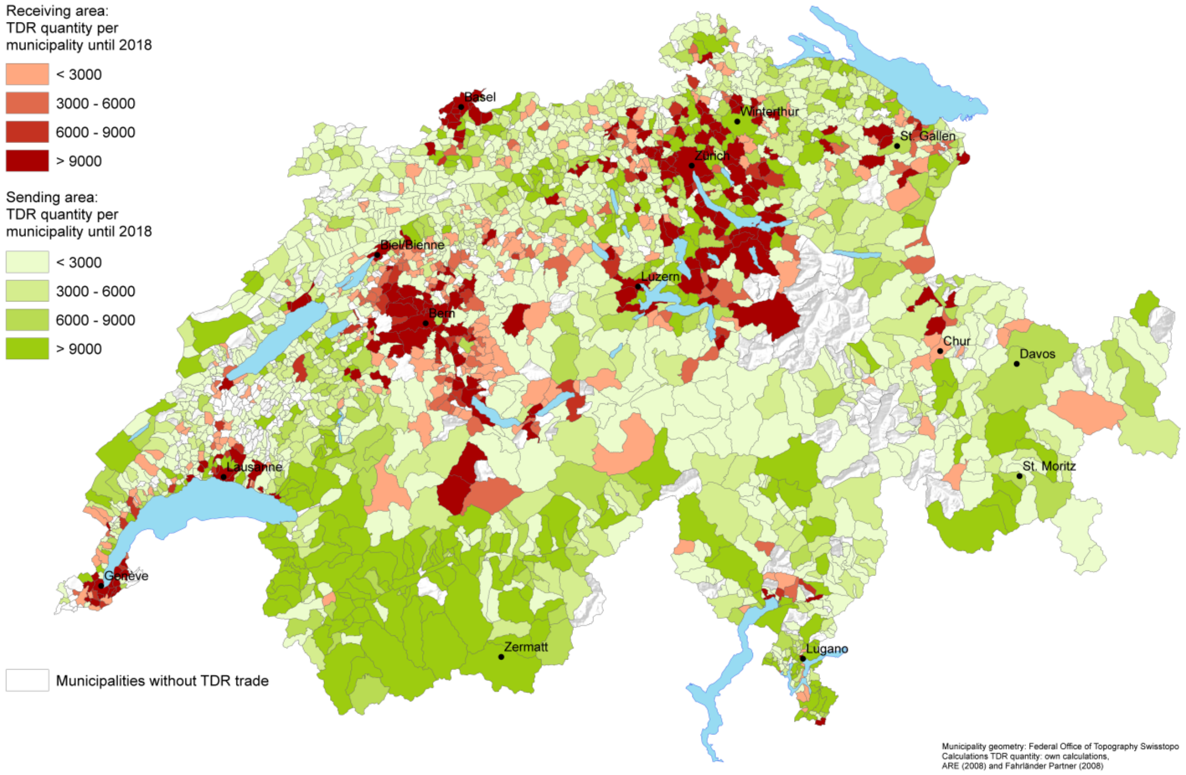
[118] According to the municipality type definition of Wüest & Partner AG (2011). The definition is based on the municipality type definition of the Swiss Federal Statistical Office. For more information see: http://www.bfs.admin.ch/bfs/portal/de/index/infothek/nomenklaturen/blank/blank/gemtyp/01.html, accessed: 2012-08-13.

Industrial municipalities (e.g. Erlach, Vionnaz)	4.49	1,238,771	0.32	116,390
Agricultural municipalities (e.g. Lauenen, Yens)	3.97	1,000,035	0.55	164,781
Overall (whole Switzerland)	∑ 31.88	∑ 9,174,943	∑ 20.49	∑ 9,034,348

Table C-2: Characteristics (canton level) of the sending and receiving areas for the year 2018 (own calculations, data basis: ARE, 2008 and Fahrländer Partner, 2008).

Canton	**Sending area**		**Receiving area**	
	Area (in km2)	**Assigned TDR quantity**	**Area (in km2)**	**Assigned TDR quantity**
Zürich	1.58	640,082	5.23	2,751,866
Bern / Berne	0.76	231,376	4.33	1,761,932
Luzern	0.86	299,286	0.51	262,332
Uri	0.06	18,242	0.08	31,999
Schwyz	0.14	55,412	0.65	266,763
Obwalden	0.07	24,970	0.00	834
Nidwalden	0.08	29,678	0.23	89,660
Glarus	0.00	0	0.02	8,468
Zug	0.12	62,131	0.32	131,434
Fribourg / Freiburg	2.71	702,542	0.28	106,360
Solothurn	1.56	487,791	0.02	6,728
Basel-Stadt	0.01	4,468	0.30	221,568
Basel-Landschaft	0.55	190,230	1.10	454,228
Schaffhausen	0.24	85,578	0.13	53,659
Appenzell Ausserrhoden	0.05	14,842	0.12	40,559
Appenzell Innerrhoden	0.03	8,335	0.06	22,948
St. Gallen	0.85	261,362	0.50	167,716
Graubünden / Grigioni / Grischun	1.18	408,396	0.10	39,864
Aargau	1.84	631,325	1.45	577,612

Thurgau	1.11	360,562	0.04	12,733
Ticino	2.63	942,180	0.32	130,161
Vaud	4.82	1,157,783	2.35	961,932
Valais / Wallis	9.41	2,249,384	0.01	1,545
Neuchâtel	0.60	165,286	0.41	179,867
Genève	0.13	38,691	1.92	749,169
Jura	0.49	105,012	0.01	2,411
Overall (whole Switzerland)	∑ 31.88	∑ 9,174,943	∑ 20.49	∑ 9,034,348



Municipality geometry: Federal Office of Topography Swisstopo
Calculations TDR quantity: own calculations,
ARE (2008) and Fahrländer Partner (2008)

Fig. C-1: Spatial distribution of sending and receiving areas in Switzerland.

C.2 Additional results of setting 3

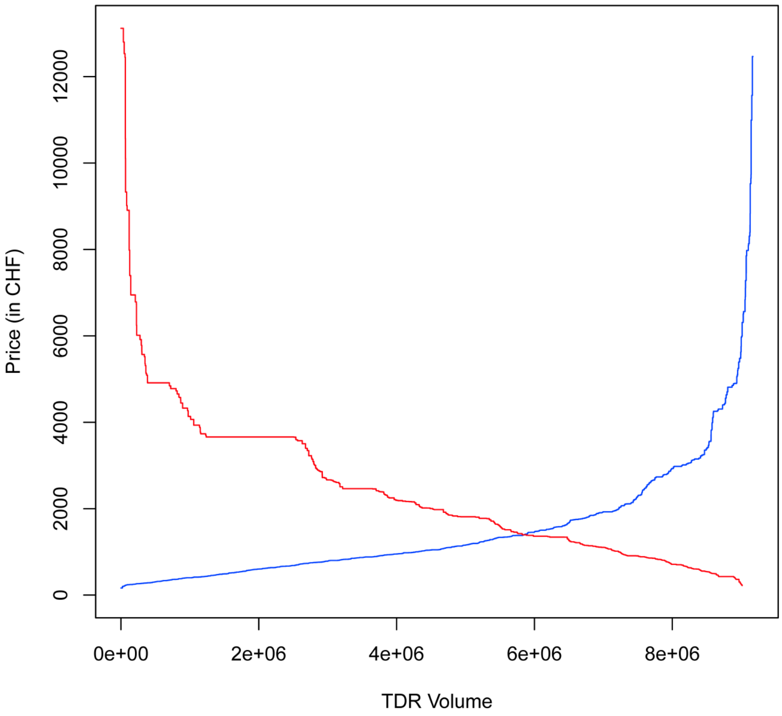
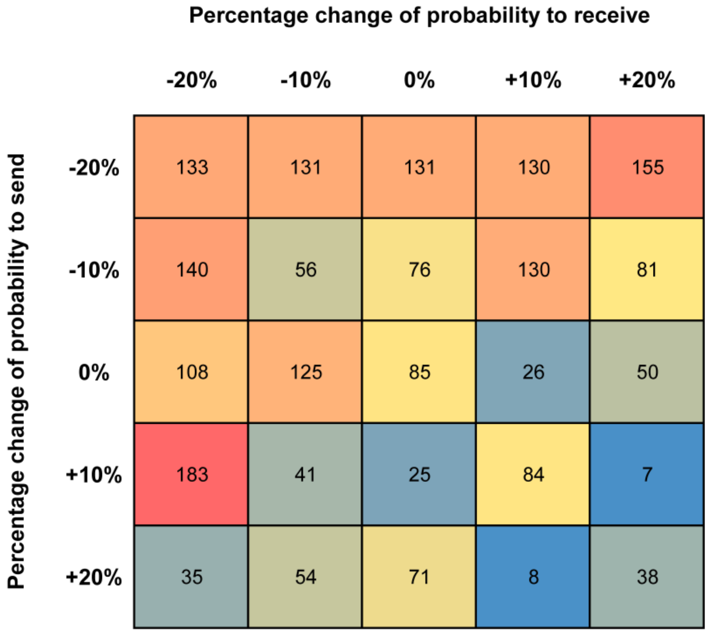


Fig. C-2: Supply (blue) and demand (red) for TDR in the first auction (setting 3).

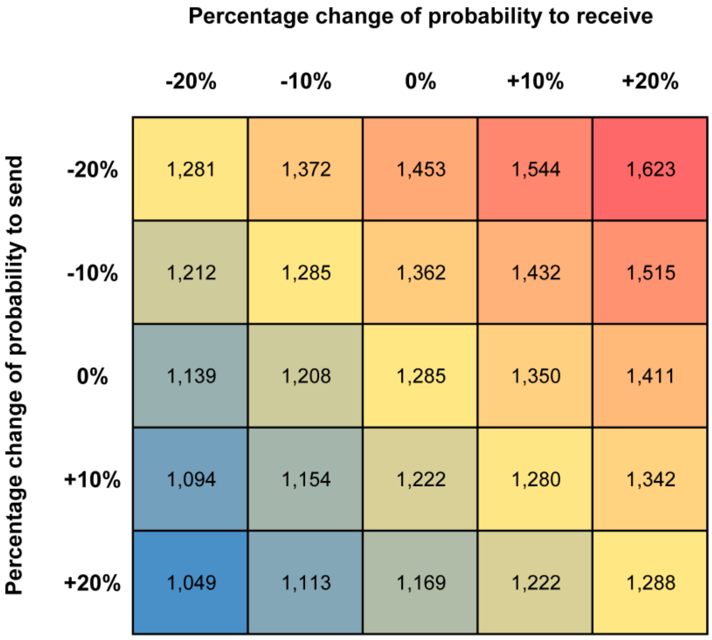
C.3 Additional results of setting 4



Percentage change of probability to receive

Percentage change of probability to send	-20%	-10%	0%	+10%	+20%
-20%	133	131	131	130	155
-10%	140	56	76	130	81
0%	108	125	85	26	50
+10%	183	41	25	84	7
+20%	35	54	71	8	38

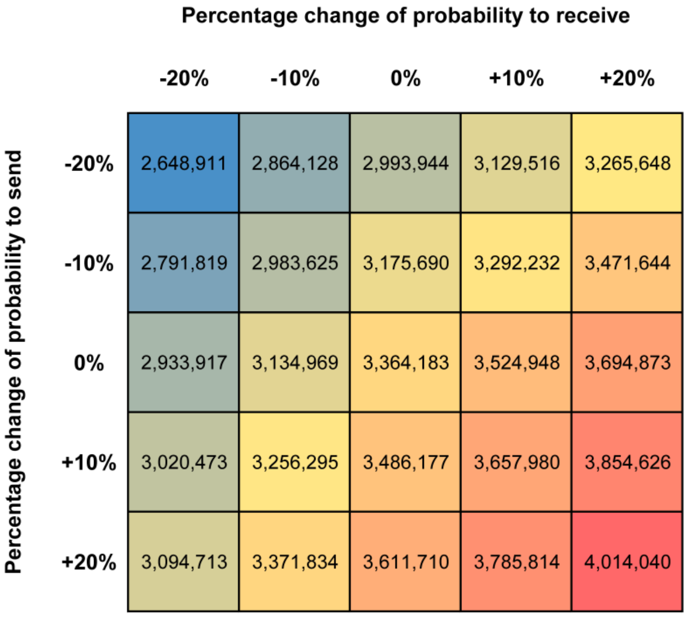
Fig. C-3: Effect of percentage change of parameters p_{send} and $p_{receive}$ on the variance of the clearing price in the first auction.



Percentage change of probability to receive

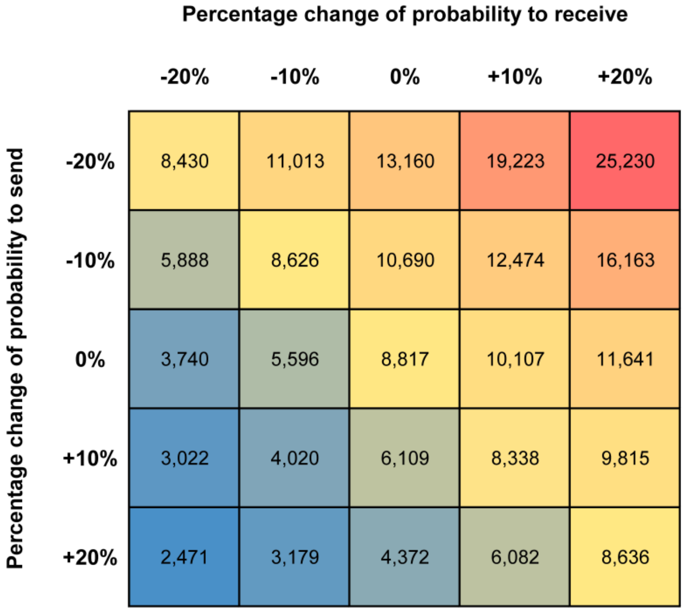
Percentage change of probability to send	-20%	-10%	0%	+10%	+20%
-20%	1,281	1,372	1,453	1,544	1,623
-10%	1,212	1,285	1,362	1,432	1,515
0%	1,139	1,208	1,285	1,350	1,411
+10%	1,094	1,154	1,222	1,280	1,342
+20%	1,049	1,113	1,169	1,222	1,288

Fig. C-4: Effect of percentage change of parameters p_{send} and $p_{receive}$ on the average clearing price over 5 auctions.



	-20%	-10%	0%	+10%	+20%
-20%	2,648,911	2,864,128	2,993,944	3,129,516	3,265,648
-10%	2,791,819	2,983,625	3,175,690	3,292,232	3,471,644
0%	2,933,917	3,134,969	3,364,183	3,524,948	3,694,873
+10%	3,020,473	3,256,295	3,486,177	3,657,980	3,854,626
+20%	3,094,713	3,371,834	3,611,710	3,785,814	4,014,040

Fig. C-5: Effect of percentage change of parameters p_{send} and $p_{receive}$ on the TDR quantity sold in the five auctions.



	-20%	-10%	0%	+10%	+20%
-20%	8,430	11,013	13,160	19,223	25,230
-10%	5,888	8,626	10,690	12,474	16,163
0%	3,740	5,596	8,817	10,107	11,641
+10%	3,022	4,020	6,109	8,338	9,815
+20%	2,471	3,179	4,372	6,082	8,636

Fig. C-6: Effect of percentage change of parameters p_{send} and $p_{receive}$ on the variance of the clearing price over 5 auctions

C.4 Additional results of setting 5

Table C-3: Descriptive statistics of the data used in the regression model for estimating the building zone price per municipality.

Variable name	Description[a]	Source[b]	Minimum	Maximum	Mean	S.D.
BLP	Building zone price in CHF per square meter (median price of municipality) (2010)	A	60.00	3,430.00	497.20	454.87
SecondRes	Percentage of second homes (2011)	B	0.00	93.53	18.48	17.03
Income	Total net income of natural persons in million CHF (2008)	E	0.34	15,819.69	111.40	427.05
Accessibility	Average (private motorized transport) accessibility[c] (logarithmic transformed values) (2005)	F	4.66	13.81	9.47	0.98
GFloorA	Median gross floor area in square meter (2010)	A	0.00	325.2	111.57	58.91
OccDens	Occupation density (number of residences divided by population) (2011)	B	0.00	21.60	0.50	0.59
InCommuter	Inward commuters (2000)	D	0.00	214,788.00	1,014.69	6,013.30
PerSec1	Percentage of full-time equivalents in sector 1 to all other sectors (2008)	C	0.00	100.00	20.60	21.48
PerSec2	Percentage of full-time equivalents in sector 2 to all other sectors (2008)	C	0.00	100.00	31.24	19.50
PerSec3	Percentage of full-time equivalents in sector 3 to all other sectors (2008)	C	0.00	100.00	48.17	21.52
Altitude	Altitude of settlement center in meters above sea level (2010)	B	196.00	1954.00	621.42	271.63
Radiation	Mean of global radiation in watt per square meter[d] (2010)	G	38.79	87.11	55.30	10.93
MunType1	Dummy for municipality type 1: Large cities	A, B	0.00	1.00	0.00	0.04
MunType2	Dummy for municipality type 2: Medium-sized cities	A, B	0.00	1.00	0.01	0.09

MunType3	Dummy for municipality type 3: Small cities	A, B	0.00	1.00	0.03	0.16
MunType4	Dummy for municipality type 4: Rich municipalities	A, B	0.00	1.00	0.03	0.18
MunType5	Dummy for municipality type 5:Tourist municipalities	A, B	0.00	1.00	0.06	0.23
MunType6	Dummy for municipality type 6:Inner agglomeration belt of large cities	A, B	0.00	1.00	0.07	0.26
MunType7	Dummy for municipality type 7: Outer agglomeration belt of large cities	A, B	0.00	1.00	0.09	0.29
MunType8	Dummy for municipality type 8: Inner agglomeration belt of medium-sized cities	A, B	0.00	1.00	0.05	0.22
MunType9	Dummy for municipality type 9: Outer agglomeration belt of medium-sized cities	A, B	0.00	1.00	0.07	0.26
MunType10	Dummy for municipality type 10: Commuter municipalities outside agglomerations	A, B	0.00	1.00	0.21	0.41
MunType11	Dummy for municipality type 11: Industrial municipalities	A, B	0.00	1.00	0.11	0.32
MunType12	Dummy for municipality type 12: Agricultural municipalities[e]	A, B	0.00	1.00	0.27	0.44

[a] All variables are on municipality level. The year is noted in parentheses.

[b] Data sources: A: Wüest und Partner (2011); B: Federal Statistical Office (2011); C: Federal Statistical Office (2008); D: Federal Statistical Office (2000); E: Federal Tax Administration (2008); F: Federal Office for Spatial Development (2005); G: Federal Office of Meteorology and Climatology (2010).

[c] Sum of the weighted opportunities (here: population). For more information see: http://e-collection.library.ethz.ch/eserv/eth:28945/eth-28945-01.pdf, accessed: 10-19-2012.

[d] The values represent mean daily, monthly and yearly quantities of Surface Incoming Shortwave (SIS) radiation in watt per square meter (also known as global radiation). For more information see: Dürr et al. (2010).

[e] This municipality type 12 is not listed in Table C-4 because it was chosen as reference for the estimation of the coefficients of the other municipality types.

Table C-4: Determinants of the regression model for estimating the building zone price per municipality[a].

Variable name	**Coefficients**	**t-values**
Constant	-744.667***	-6.845
SecondRes	0.423	0.588
Income	0.543***	10.972
Accessibility	60.663***	6.348
GFloorA	1.194***	7.585
OccDens	-11.256	-1.114
InCommuter	-0.026***	-5.625
PerSec2	-1.701***	-4.609
PerSec3	0.808**	2.127
Altitude	-0.167***	-5.055
Radiation	9.326***	13.959
MunType1	-1,222.876	-1.530
MunType2	-262.008	-1.533
MunType3	89.745	1.126
MunType4	1,274.228***	23.153
MunType5	89.643	1.125
MunType6	582.986***	10.540
MunType7	380.661***	10.394
MunType8	49.045	1.020
MunType9	-75.456**	-2.179
MunType10	74.020***	3.103
MunType11	44.016	1.381
*SecondRes *MunType1*	157.782***	3.126
*SecondRes *MunType2*	28.442**	2.483
*SecondRes *MunType3*	-9.765**	-2.054
*SecondRes *MunType4*	-3.495	-1.084

*SecondRes *MunType5*	1.878	1.284
*SecondRes *MunType6*	2.119	0.418
*SecondRes *MunType7*	5.118*	1.793
*SecondRes *MunType8*	-0.228	-0.066
*SecondRes *MunType9*	1.944	1.293
*SecondRes *MunType10*	-2.649**	-2.340
*SecondRes *MunType11*	-2.252**	-1.991
*GFloorA*OccDens*	-0.817***	-3.238
Number of observations	2,585	
R^2	0.673	
Adjusted R^2	0.669	

[a] Significance levels (two-tailed): *** 1%, ** 5%, * 10%.

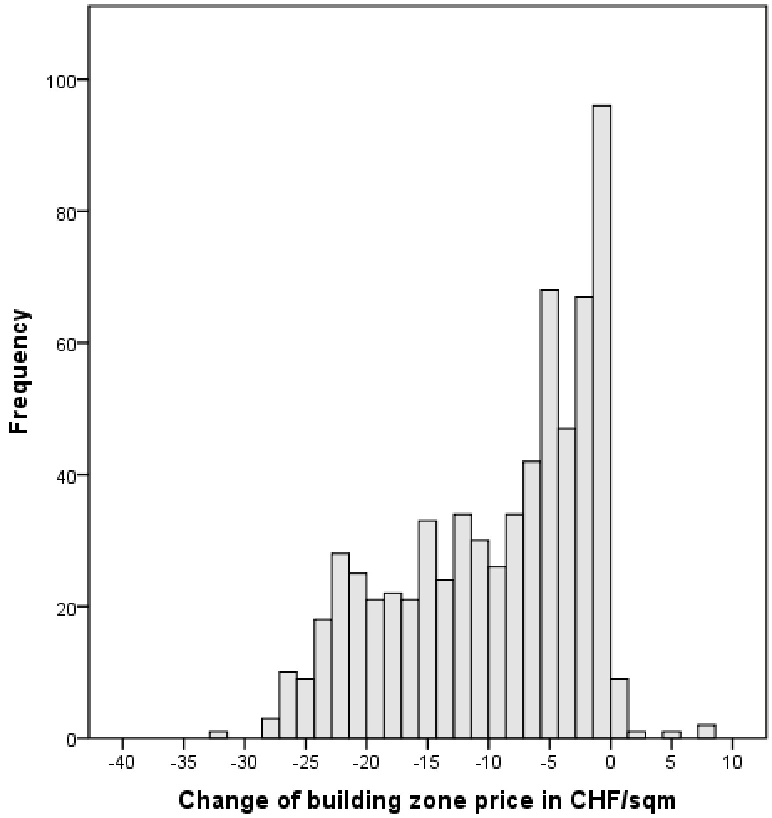


Fig. C-7: Histogram of the change of building zone prices (differences compared to the original building zone prices) due to the 'popular initiative on second homes'.

Curriculum vitae

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Born August 23, 1982 in Chur, Switzerland

Citizen of Poschiavo (GR) and Domat/Ems (GR), Switzerland

Academic Education

11/2009 - 04/2013:	Doctoral Program in Civil and Environmental Engineering EDCE at École Polytechnique Fédérale de Lausanne EPFL
	PhD-student at the Swiss Federal Institute WSL (Research Unit Economics and Social Sciences)
01/2012 - 03/2012:	Postgraduate Research Program in Real Estate and Planning (3 months) at Henley Business School, University of Reading (UK)
10/2006 - 06/2008:	Studies in Geography, University of Zurich (Master of Science in Geography, Major in Geographic Information Sciences GIS)
03/2003 - 08/2006:	Studies in Geography, University of Zurich (Bachelor of Science in Geography)
08/1997 - 07/2002:	Swiss Matura (“Typus C”), Kantonsschule Chur

Working Experience

11/2009 - present:	PhD-student at the Swiss Federal Institute WSL (Research Unit Economics and Social Sciences)
07/2008 - 10/2009:	Geomarketing Consultant (GIS-Specialist) at AZ Direct AG, St. Gallen and dr-huldi-management.ch, Rotkreuz
09/2007 - 03/2008:	Tutorial Assistant (part-time) at the Institute for Transport Planning and Systems (IVT), ETH Zurich
02/2007 - 09/2007:	Internship at Ernst Basler + Partner AG (Business Field: Information Technology and GIS), Zurich
09/2004 - 03/2005:	Tutorial Assistant (part-time) at the Institute of GIS/GIVA, University of Zurich

Courses and activities outside PhD Program

01/2013: SNSF-media training for researcher, MAZ Lucerne

01/2012 - 03/2012: Housing Economics (PhD and master’s course), Henley Business School, University of Reading (UK)

08/2011: Swiss Summerschool in Statistics (Applied Analysis of Variance and Linear Modelling), University of Lugano

09/2010: Presenting – Publishing – Communicating“ (PhD course), ETH Zurich

08/2010 - 08/2012: Member of the employee representation (“Personalvertretung”) as elected PhD students’ representative at Swiss Federal Institute WSL

Publications (outside PhD thesis)

Menghini, G., Carrasco, N., Schüssler, N., Axhausen, K.W., 2010. Route choice of cyclists in Zurich, Transportation Research A: Transportation Research Part A: Policy and Practice, 44(9), 754-765.

Conferences during doctorate

World Congress of Regional Science Association International, Timisoara (Romania), 9-12 May 2012. (*Paper presented*)

ENHR-Housing Economics Workshop, Vienna (Austria), 22-24 February 2012. (*Paper presented*)

Research Seminar in Real Estate and Planning, Henley Business School, University of Reading, Reading (England), 15 February 2012. (*Paper presented*)

SwissLab 2011, Schweizerische Studiengesellschaft für Raumordnung und Regionalpolitik ROREP, Monte Verità (Ascona, Switzerland), 9-12 February 2012. (*Paper presented*)

Forum für Wohnen, KKL Lucerne (Switzerland), 23-24 September 2011. (*Co-organisation of Workshop*)

Waldökonomisches Seminar, Möglichkeiten und Grenzen der Analyse von Holzmärkten, Münchenwiler (Switzerland), 5-6 September 2011. (*Participation*)

Raum+ Schwyz: Siedlungsflächenpotenziale für eine Siedlungsentwicklung nach Innen, ETH Zurich, 26 March 2010. (*Participation*)

„Unendliche Weiten? Optionen zum Flächensparen“, Loccum (Germany), 12-14 October 2009. (*Participation*)