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Results of an agent-based market simulation for transferable development rights (TDR) in Switzerland

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Abstract. Transferable development rights (TDR) are discussed or applied in various countries for a wide variety of purposes: notably to increase building densities, preserve natural areas, compensate reduced development possibilities, and 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 problems with the spatially imbalanced supply and demand of existing undeveloped building zones. Our aim is to briefly introduce a TDR market concept for Switzerland, present an empirically calibrated agent-based TDR market simulation, and finally analyze the detailed simulation results. We ran the simulation with four different settings which allowed an analysis of relevant political and economic questions for Switzerland. The results show that the TDR prices were comparable with existing land prices in Switzerland. 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 of 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.

Keywords: transferable development rights (TDR), TDR market, agent-based modeling (ABM), market simulation, market clearing price

1 Introduction

Transferable development rights (TDR)—a market-oriented planning instrument—have been discussed since the late 1960s.(1) The instrument is widespread in the USA, and also partially applied or at least discussed in about another dozen countries worldwide (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).

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(1) 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).

In Switzerland TDR might be applied as an instrument to reduce the land-use problems related to the unsustainable development of settlement areas and to manage the problems caused by an imbalanced supply and demand of existing undeveloped building zones.

The problem with the spatially imbalanced supply and demand of undeveloped building zones is caused mainly by the permissive zoning practice of many municipalities and toleration of unlawful situations by authorizing public institutions (at cantonal and federal level). In the past, many municipalities—mainly in rural areas—have designated overlarge building zones with low densities. This practice was primarily intended to be an incentive for the influx of certain population groups and new tax revenues. However, this policy ignored the Swiss Federal Law on Spatial Planning(2) and led to an exceptionally strong imbalance of supply and demand for undeveloped building zones. In the next thirty years, in urbanized areas and along major transport routes the estimated demand will considerably exceed the current reserves, whereas in rural areas the reserve of undeveloped building zones is significantly larger than the calculated demand (ARE, 2008; Fahrländer Partner AG, 2008).

In order to solve this imbalance and to reduce the high land consumption the Swiss parliament proposed a revision of the Swiss Federal Spatial Planning law which was accepted on 3 March 2013 in a popular vote. The revision includes, among other things, downzoning(3) building zones for which there will be no demand in the next fifteen years.

In Switzerland, in many cases the landowners whose parcel is to be downzoned will have to be compensated fully because changing its status from building zone to agricultural zone is a form of material expropriation. Many municipalities and cantons cannot finance this.(4) 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 [see the calculations of Fahrländer Partner AG (2008)]. It is doubtful whether these municipalities will have the financial means to put the proposed downzoning into practice.

A solution to reduce these problems is TDR. They allow the transferring of development rights, and the result of such transfers is equivalent to 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, see also subsection 2.2.3) compared with the density in the sending area.

Menghini (2013) proposes both a concept for a Swiss TDR market and an agent-based model (ABM) for simulating the proposed market (called TDR-ABM). The concept was discussed in a workshop(5) with spatial planning and real-estate experts, and therefore it includes ideas and suggestions from landowners involved in such a potential market. The agent-based simulation was developed to assess the demand, supply, and prices in such a market.

An ABM was chosen—instead of, for example, a pure analytical method—because of the heterogeneous participants(6) in the TDR market. With an ABM it is possible to model

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(2) 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 fifteen years.

(3) The practice of reducing the level of zoning of land from building to agricultural zone.

(4) 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 twenty years, only 36% (10 000 ha) of the unwanted existing building zones could be downzoned.

(5) Participants were experts from local authorities (confederation/canton/municipality), banks, real-estate companies, a planning association, and academics.

(6) Here, the market participants (agents) represent landowners of different categories such as enterprises (eg, banks), individual persons, social organizations (eg, cooperatives), or the state.

individual decision making and human behavior (eg, the degree of rationality, risk aversion, learning abilities) which is essential for simulating the TDR market. Furthermore, it is possible to consider special variables or parameter distribution patterns or to reduce random effects (eg, probability of participating in the TDR market) by running the simulation many times (eg, 100 times) and then averaging the results of all runs. However, up to this point, the simulation has not been calibrated with empirical data and therefore lacks empirical validation.

ABMs have been applied successfully in several land-use-related applications such as policy analysis and planning (eg, Happe et al, 2006), participatory modeling (eg, D'Aquino et al, 2003), explaining spatial patterns of land use or settlement (eg, Parker and Meretsky, 2004), testing social and economic science concepts (eg, Polhill et al, 2001), examining the influence of agents on urban land-use dynamics and land markets (eg, Filatova et al, 2009), or for modeling land-use functions (eg, An et al, 2005).(7) Besides these examples, ABMs have also been applied successfully in other areas such as simulating electricity markets (eg, see Sennsfuss et al, 2007), stock markets (eg, see LeBaron, 2002), or housing markets (eg, see Erlingsson et al, 2013).

Our aim 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 an implementation of a TDR market and will, therefore, inform the public and expert debate.

In the next section we present in detail the TDR market concept, the data preparation, and the calculations for the study area. The research questions are presented in subsection 2.3. Afterwards (section 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), a discussion of the main findings (section 5), and conclusions (section 6).

2 Applying TDR in Switzerland

2.1 TDR market concept

We present the central features of the proposed TDR market.(8) The design of the TDR market focuses on the imbalanced supply and demand of the existing building zones and proposes to reduce this problem by trading development rights, 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).

Ideally, the designation of appropriate sending and receiving areas would 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 fifteen years. The receiving areas consist of parcels not yet designated as building zones, which should—in accordance with the Swiss law—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 the grandfathering principle). Those landowners

(7) For more information about ABMs related to land use and/or land markets see, for example, Brown et al (2004), Brown and Robinson (2006), Ettema (2011), Filatova et al (2013), Magliocca et al (2011), Matthews et al (2007), Parker and Filatova (2008), or Robinson et al (2013); for a more general overview of ABMs see, for example, Gilbert (2007) or North and Macal (2007).

(8) The ABM we use in this paper is presented in Menghini (2013). There, the concept and terms of the ODD protocol (Grimm et al, 2010) are followed. Here, we abstain from using the ODD protocol for reasons of length, yet we inform the reader which elements are presented where in this paper: purpose of the model: section 1; entities, state variables, and scales: subsection 3.1 and table 2; process overview and scheduling: figure 2; design concepts: subsections 3.2 to 3.4; initialization: subsections 3.2 to 3.4; input data: subsection 2.2, figure 1.

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 parcel's size and the allowed utilization factor (see subsection 2.2.3). Moreover, the TDR per parcel have to be sold or bought as a whole (called the 'TDR bundle'). This is an incentive for the receivers to develop the maximum allowable gross floor area (9) per parcel (high-density development), and the senders are fully compensated for the loss of their development possibility in a single transaction.

The TDR are traded on a 'TDR platform' (called 'trading agent') following the rules of a multiunit double auction with a uniform price. Each landowner of the sending or receiving area can submit (voluntary participation), respectively, an ask (sender) with the desired price per TDR or a bid (receiver) with the price he or she 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 order and the bids in descending order and calculates the market clearing price. The market price is at the intersection of the ask and bid curves. This means that the price for any development right will be the same throughout the country (market) in one trading period. Heterogeneity of land values will be reflected in different numbers of TDR assigned to each parcel in accordance with the utilization factor and, hence, in the theoretical price of a tradable development right (PTDRtheoretical) (see subsection 3.3). Besides this, a uniform market price is also intended to some degree as the trading system should result in a development that focuses areas where utility of land is highest.

All sender agents who asked a price below or equal to the market clearing price and all receiver agents who bid a price above or equal to 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.

It is suggested that there should be two rounds of five auctions,(10) with one year between each auction. The reasons for this choice are manifold: (11) (1) The time required to organize five auctions (five years) allows the municipalities to adapt their zoning plans, that is, to designate sending and receiving areas, for the next round. (2) The frequency of one year between the auctions represents the average time required to plan a housing project. (3) The auctions are only conducted once a year in order to encourage the market participants to bid more truthfully, as it will be a long time before the next trading opportunity. (4) The TDR market price might not fluctuate as much as it would in the case of continuous double auctions. (5) The resulting TDR market prices of each auction could be taken as a reference for the market participants when determining their ask and bid prices (although in our simulation adaptations based on previous market prices have not been considered).

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(9) Also known as 'living area'.

(10) In the TDR–ABM we simulate only one round with five auctions.

(11) The auction design (eg, number of auctions, time between the auctions) has been defined and elaborated in two expert workshops: one with spatial planning and real-estate experts (see footnote 5), and one with auction design specialists.

2.2 Study area, data preparation, and research questions

Switzerland covers an area of 41 284.9 km^2 of which 6.8% is settlement area (SFSO, 2010a). Around 82% of the settlement area consists of building zones (2270 km^2).(12) Of this area, between 378 km^2 and 528 km^2 (17% to 24%)(13) have not been developed. According to ARE (2008) and Fahrländer Partner AG (2008) these undeveloped building zones could provide space for about two million additional inhabitants. Switzerland has a present population of 8 million inhabitants and current predictions (medium scenario) are that a peak will be reached in 2055 at 9 million inhabitants (SFSO, 2010b).

2.2.1 *Designation of sending and receiving areas*

Following existing analyses of supply (ARE, 2008) and demand (Fahrländer Partner AG, 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.(14) 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 AG (2008) was reduced by considering the development potential not used so far (the additional gross floor area that can be realized without TDR).(15) According to a study of the canton of Zurich between 1993 and 2005, 54% of the newly built floor area was realized in already developed building zones by using the available development potential (inner densification) (Kanton Zürich, 2007). As the overall pressure for using this potential (in German, *Innere Verdichtung*) is rather lower outside Zurich, it was assumed for the whole of Switzerland that at most 40% of the demand could be realized by using the inner development potential.(16) (3) Since the supply and demand datasets are based on different years,(17) we scaled them linearly(18) so that both datasets represent the same year of origin. (4) The total sending area (considering all municipalities) has been capped(19) so 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 is 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 (see subsection 2.2.2).

On the basis of 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 or it was assigned to the receiving area if the projected demand exceeds the supply of undeveloped building land.

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(12) The residential zone area is 1054 km^2, of which 183 km^2 to 277 km^2 have not been developed.

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

(14) We are interested in the possible impacts of five auctions from 2013 to 2018 (end of 2017), which results in five auctions under the assumption that one auction takes place each year. For that purpose we calculate the potential sending and receiving area that would be available for the year 2018.

(15) In Switzerland landowners, typically, do not realize the development density permitted by law. Thus, there is potential to build much more densely.

(16) The Institute for Spatial Development at ETH Zurich (IRL) is about to develop a detailed method to identify inner development potentials in settled areas (eg, unbuilt sections between settled areas). As, so far, the investigation covers only a few cantons, we did not use the partial results but made a rough estimation. For more information see: http://www.raumplus.ethz.ch

(17) The study by Fahrländer Partner AG (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).

(18) We assumed a linear increase/decrease of the aggregated demand/supply values over time.

(19) In proportion to the area of undeveloped building zone parcels per municipality.

2.2.2 *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 twenty years (Wüest and Partner AG, 2011), and digital cadastral data from the Cantons of Zurich and Thurgau.

2.2.3 *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 [see equation (1) in subsection 3.3].

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) in the Cantons of Zurich and Fribourg. The following landowner categories are distinguished:
(1) Enterprises(20) operating in the commercial real-estate market (*enterprises*).
(2) Confederation/cantons/municipalities/social organizations(21) (*nonprofit institutions*, NPI).
(3) Individuals/married couples/simple partnerships(22) (*individuals*).

The characteristics of the sending and receiving areas for the year 2018 are summarized in table 1. A more detailed description (characteristics per municipality type and canton) can be found in appendix A (see table A1).

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

	Number of parcels	Area (km^2)	Assigned TDR[a] quantity
Sending area	30 195	31.88	9 174 943
Receiving area	19 264	20.49	9 034 348

[a] TDR—transferable development rights.

2.3 Detailed research questions

On the basis of the facts and situation presented above, 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%?

3 TDR market simulation model (TDR–ABM)

In this section the basics of the TDR–ABM are explained [for more details see Menghini (2013)]. The calibration of the model with the survey data is described in subsection 3.3.

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(20) For example, corporation, limited liability partnership, bank, insurance company.

(21) For example, cooperative, association.

(22) It is supposed that architects and real-estate developers represent the interests of individuals, married couples, and simple partnerships.

3.1 Agents' description

The simulation model TDR–ABM[23] distinguishes three main types of agent: two types representing landowners in the sending and receiving area (called sender agents or senders, receiver agents or receivers) and one type representing the market platform (trading agent). Each agent is characterized by different attributes (state variables, eg, parcel area) and behavior (eg, price adaption coefficients) derived from existing data and from a dedicated questionnaire survey. The questionnaire survey data are used to define realistic behavior of

Table 2. State variables of sender and receiver agents (differing variables of sender and receiver agents are highlighted).

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 m^2): $\boldsymbol{A} \in \mathbb{R}^+$	Parcel area (in m^2): $\boldsymbol{A} \in \mathbb{R}^+$	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 land price in CHF per m^2 (in municipality): $\boldsymbol{BLP} \in \mathbb{R}^+$	Building zone price in CHF per m^2 (in municipality): $\boldsymbol{BLP} \in \mathbb{R}^+$	own calculation based on (A)
Agricultural land price in CHF per m^2 (in municipality): $\boldsymbol{ALP} \in \mathbb{R}^+$	Agricultural land price in CHF per m^2 (in municipality): $\boldsymbol{ALP} \in \mathbb{R}^+$	own calculation based on (B)
Current sender-agent state: $\boldsymbol{s}_{\mathbf{s}}$ {"notyetsending", "sending", "sent"}	Current receiver-agent state: $\boldsymbol{s}_{\mathbf{r}}$ {"notyetreceiving", "receiving", "received"}	own calculation
Quantity of TDR to sell: $\boldsymbol{q}_{\mathbf{s}} \in \mathbb{N}_0$	Quantity of TDR to buy: $\boldsymbol{q}_{\mathbf{r}} \in \mathbb{N}_0$	own calculation based on (A), (B)
Probability to enter into the sending and trading process: $\boldsymbol{p}_{\mathbf{send}} \in [0,1] \subset \mathbb{R}_0^+$	Probability to enter into the receiving and trading process: $\boldsymbol{p}_{\mathbf{receive}} \in [0,1] \subset \mathbb{R}_0^+$	own calculation based on (C)
Current ask price in CHF per TDR (CHF per saleable m^2 of building area that potentially can be developed): $\boldsymbol{p}_{\mathbf{ask}} \in \mathbb{R}^+$	Current bid price in CHF per TDR (CHF per purchasable m^2 of building area that potentially can be developed): $\boldsymbol{p}_{\mathbf{bid}} \in \mathbb{R}^+$	own calculation based on (C)
Ask price initialization coefficients: $\boldsymbol{\beta}_{\mathbf{ask}\,i} \in \mathbb{R}^+$, where $i \in$ {"ParcelArea", "PTDRtheoretical"}	Bid price initialization coefficients: $\boldsymbol{\beta}_{\mathbf{bid}\,i} \in \mathbb{R}^+$, where $i \in$ {"ParcelArea", "PTDRtheoretical"}	own calculation based on (C)
Ask price initialization constant: $\boldsymbol{C}_{\mathbf{ask}} \in \mathbb{R}^+$	Bid price initialization constant: $\boldsymbol{C}_{\mathbf{bid}} \in \mathbb{R}^+$	own calculation based on (C)
Ask price adaptation coefficient: $\boldsymbol{a}_{\mathbf{ask}} \in \mathbb{R}^+$	Bid price adaptation coefficient: $\boldsymbol{a}_{\mathbf{bid}} \in \mathbb{R}^+$	own calculation based on (C)
Surplus of realized trade in CHF: $\boldsymbol{sur} \in \mathbb{R}^+$	Surplus of realized trade in CHF: $\boldsymbol{sur} \in \mathbb{R}^+$	own calculation

[a] Data sources: (A) Database of more than 91 000 transactions of building zone parcels over the last 20 years (Wüest and 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 (see Menghini, 2013).

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[23] 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).

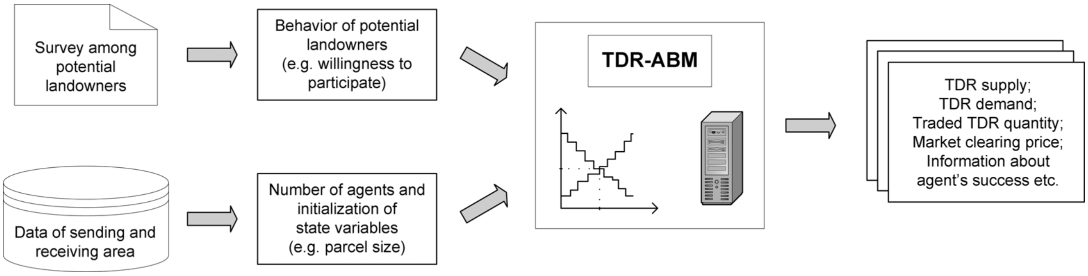

Figure 1. Overview of the data basis of the TDR–ABM (transferable development rights–agent-based modeling).

the market participants (eg, 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 2. The data basis used is illustrated in figure 1, and the central variables of the trading agent are listed in subsection 3.4. Moreover, figure 2 illustrates all agents' states and transitions, actions, and communication for iteration *t*.

3.2 The calibration of the agents' behavior

In order to simulate behavior of potential market participants realistically, the behavior of sender and receiver agents has been calibrated with results of a participant-specific questionnaire survey[24] (TDR survey) among a total of 1976 spatial planning and real-estate professionals in Switzerland. The contacted persons were divided into four landowner categories and each person was confronted with a unique situation description. The number of contacted professionals per landowner category and the corresponding return rate are listed in table 3. Reasons for the quite low response rate and the different numbers between the landowner categories are explained at length in Menghini et al (2013).

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

Landowner category	Number of contacted professionals[a]	Questionnaires returned by senders (%)	Questionnaires returned by receivers (%)
Enterprises operating in commercial real-estate transaction (called hereinafter enterprises)	489	35 (14.3)	25 (10.2)
Confederation/canton/municipality (called hereinafter nonprofit 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	1976	181 (18.3)	150 (15.2)

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

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[24] There exist several approaches and methods to calibrate or combine ABM with empirical data [eg, see Janssen and Ostrom (2006), Robinson et al (2007), or Smajgl et al (2011) for an overview of various methods to gather empirical data for ABM]. We used a questionnaire survey to calibrate the TDR–ABM, as this method turned out to be the most adapted and convenient for our possibilities and aims.

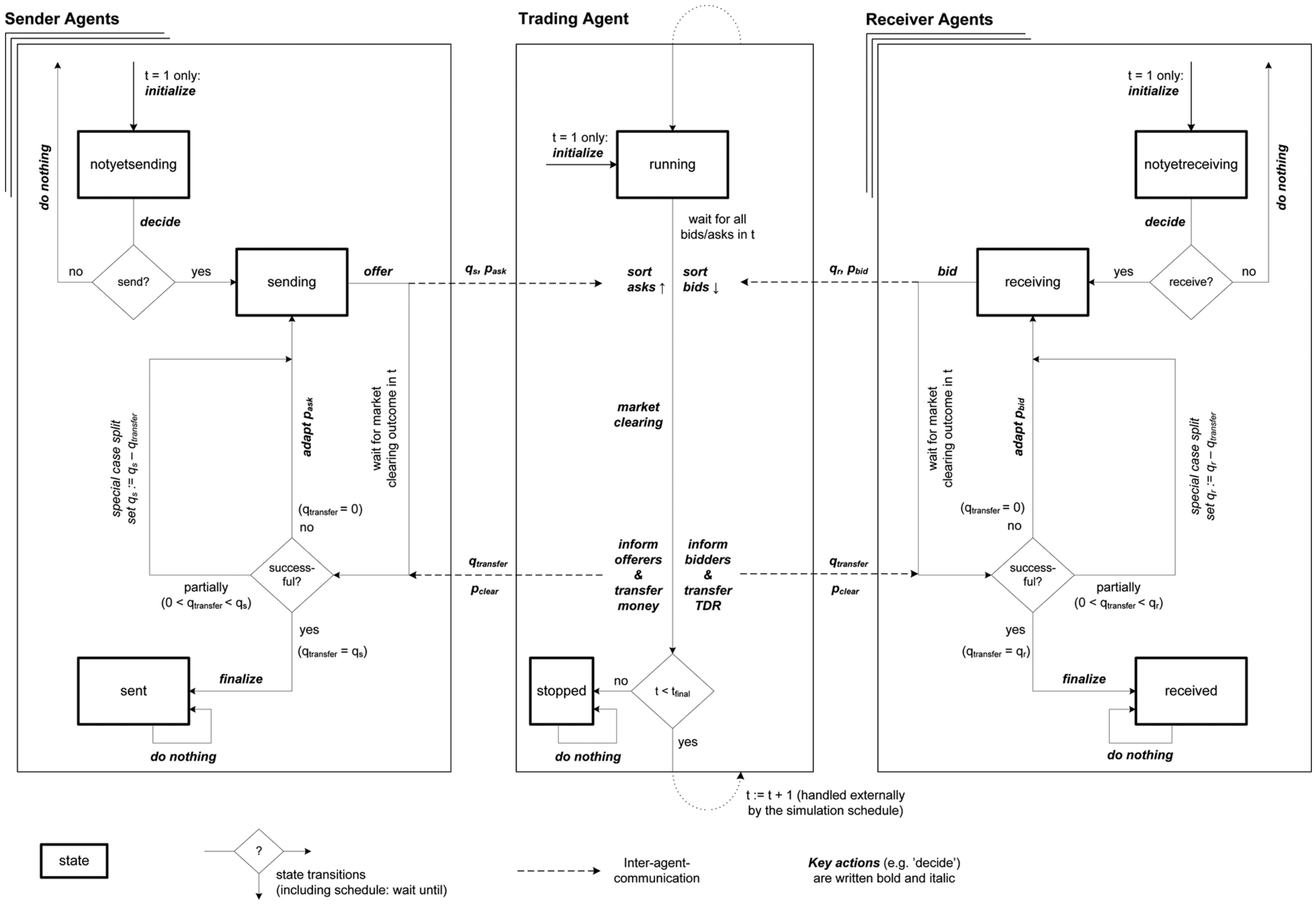

Figure 2. Agents' states and transitions, actions and communication for some iteration *t*.

In the questionnaire the respondents had to state their willingness to participate in the TDR market and their price expectations (TDR ask and bid prices) during five auctions. On the basis of this, it was possible to calculate agent-specific participation probabilities (see table 4), regression models for the TDR price determination [asks and bids; see equations (2) and (3), tables 5 and 6 below] and functions for the TDR price adaptation [see equations (7) and (8), table 7 below]. Criteria for the TDR price determination (eg, the importance of location for the estimation of the price), reasons for not participating in the TDR market were given. All questionnaire results that have been used to calibrate the TDR–ABM are listed in table 4 and tables 5–7 below .

Table 4. Sender and receiver participation probability per landowner category.

Variable name	Enterprises (%)	Nonprofit institutions (%)	Individuals (%)
p_{send}	51.4	34.8	62.5
p_{receive}	53.8	21.9	66.7

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

As described in subsection 2.1, both sender and receiver agents first decide whether or not they want to participate in the TDR market (see figure 2).(25) The assigned probability rates for each agent and landowner category are presented in table 4.

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

$$q = A\mathsf{UF} \,, \tag{1}$$

where A represents the parcel area in m^2 and UF is the utilization factor.

The general form of the functions(26) for the initialization of the TDR price are given in equations (2) (sender) and (3) (receiver). The corresponding coefficients are listed in tables 5 and 6.

$$p_{\text{ask}} = C_{\text{ask}} + \beta_{\text{ask}\,A} A + \beta_{\text{ask PTDRtheorectical}} \mathsf{PTDtheoretical} \,, \tag{2}$$

$$p_{\text{bid}} = C_{\text{bid}} + \beta_{\text{bid}\,A} A + \beta_{\text{bid PTDRtheorectical}} \mathsf{PTDtheoretical} \,, \tag{3}$$

where C_{ask} (C_{bid}) is the landowner specific ask (bid) price initialization constant, $\beta_{\text{ask}\,A}$ ($\beta_{\text{bid}\,A}$) the landowner specific ask (bid) price initialization coefficient for the parcel area A, $\beta_{\text{ask PDTRtheoretical}}$ ($\beta_{\text{bid PDTRtheoretical}}$) the landowner specific ask (bid) price initialization coefficient for the theoretical TDR value ($\mathsf{PTDRtheoretical}$). The theoretical TDR value is calculated as follows:

$$\mathsf{PDTRtheoretical} = (\mathsf{BLP} - \mathsf{ALP}) / \mathsf{UF} \,. \tag{4}$$

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(25) Note that the decision to participate in the TDR market or not can be made only in the first auction.

(26) Note that the explanatory variable AdaptationRate (Menghini, 2013) could not be considered here because the input data 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 Menghini (2013) have been recalculated without the variable AdaptationRate.

Table 5. Coefficients of the three landowner categories for initialization of the ask price.

Variable name	Enterprises	Nonprofit institutions	Individuals
C_{ask}	1263.685	735.616	243.811
$\beta_{\text{ask}\,A}$	−0.978	−0.613	−0.013
$\beta_{\text{ask PTDRtheoretical}}$	1.063	1.139	0.925

Table 6. Coefficients of the three landowner categories for initialization of the bid price.

Variable name	Enterprises	Nonprofit institutions	Individuals
C_{bid}	242.961	439.372	88.068
$\beta_{\text{bid}\,A}$	−0.008	−0.237	−0.148
$\beta_{\text{bid PTDRtheoretical}}$	0.398	0.303	0.667

All variables are defined in table 2. The theoretical TDR value can be explained as follows. For example, when the price of agricultural land is 6 CHF/m^2, the price of building zone land 500 CHF/m^2, and $\text{UF} = 0.3$, 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 = 1650 CHF/TDR (=PTDRtheoretical). To extend this example, let us further assume that a sender agent of the landowner category 'enterprise' owns a parcel of 1000 m^2 with the above mentioned properties and coefficients of table 5. In that case, the ask price would be: 1263.685−0.978 × 1000 + 1.063 × 1650 = 2040.64 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$^{(27)}$ in the first auction.

After the submission of all asks and bids (see also table 6) in the first auction (first iteration), the trading agent calculates the market clearing price (see subsection 3.4), and informs the agents about their success. The successful agents 'finalize' (see figure 2), change their state to 'sent', respectively, 'received' and calculate their surplus [equation (5) for senders, equation (6) for receivers, see figure 3]:

$$\text{sur} = (p_{\text{clear}} - p_{\text{ask}}) q_{\text{s}} , \tag{5}$$

$$\text{sur} = (p_{\text{bid}} - p_{\text{clear}}) q_{\text{r}} , \tag{6}$$

where p_{clear} represents the market clearing price (see subsection 3.4), p_{ask} (p_{bid}) the current ask (bid) price and q_{s} (q_{r}) the sold (bought) TDR quantity.

In the case of failure (too high an ask price or too low a bid price), the sender agents decrease their ask price and the receiver agents increase their bid price ('adapt' in figure 2) until their individual reservation price (resulting in the fifth auction due to agent-specific adaptation rates) is reached.

On the basis of empirical data and fitting it (Menghini, 2013), the sender agents adapt their ask prices linearly [see equation (7) and table 7] and the receiver agents exponentially [see equation (8) and table 7]:

$$p_{\text{ask}}(x) = (p_{\text{ask}} - a_{\text{ask}})\, 1.009x , \tag{7}$$

$$p_{\text{bid}}(x) = p_{\text{bid}} \exp(a_{\text{bid}} x)\, 1.009 , \tag{8}$$

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(27) The surplus is the difference between the market clearing price and the actual bid (willingness to pay), respectively, ask price (willingness to accept).

Table 7. Adaptation coefficients of the sender and receiver agents.

Variable name	Enterprises	Nonprofit institutions	Individuals
a_{ask}	5.909	9.367	9.780
a_{bid}	0.103	0.148	0.124

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.

The bid/ask price after five auctions is the reservation price.(28) This price is derived empirically through the questionnaire survey.(29) Gains from trade are made in auctions 1–4.

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 for the last twenty years (1993–2012),(30) 0.9% per year.

In parallel with the empirical survey where five auctions were proposed, the modeling was also limited to five auctions. The reason is that each modeled auction round has to be fed with empirical data—not only with agents' behavior but also with the size of sender and receiver zones—yet, the projections beyond 2018 are very vague (population, demand, prices, policies). Hence, it was decided to limit the modeled number of auctions to five.

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 outcome of each trading cycle:

(1) Market clearing price in CHF/TDR: $p_{\text{clear}} \in \mathbb{R}^+$,
(2) Total quantity of TDR supply: $q_{\text{supply}} \in \mathbb{N}_0$,
(3) Total quantity of TDR demand: $q_{\text{demand}} \in \mathbb{N}_0$,
(4) Total quantity of TDR sold (traded): $q_{\text{trade}} \in \mathbb{N}_0$.

In each auction the trading agent calculates the market clearing price p_{clear} (see figure 3) in accordance with the principle of an MDA. Since the traded TDR bundles have different sizes, in most cases, the TDR bundle of the last successful agent(31) has to be split. 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 when it is the last auction, the leftover TDR are bought or sold by the operator of the TDR market platform (eg, government).

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(28) For a discussion on reservation price for land see Parker and Filatova (2008).

(29) An example for descriptive statistical data: the mean ask (bid) price of enterprises in the first auction was CHF 1295.04 (916.08), SD 602 (479), min 487 (400), max 2500 (1875). The price change from auction 1 to auction 5 is expressed in the adaptation coefficients (table 7).

(30) We have chosen the CIP (see http://www.bfs.admin.ch/bfs/portal/en/index/themen/05/02/blank/key/basis_aktuell.html) and not a land price index as calculated in Bourbassa et al (2010). The reason is that land prices are highly volatile and, hence, taking different examples of past price increases for the future would lead to quite different results. In the long term, the increase in land prices (land price index) is closely related to the CIP development. CIP covers macroeconomic increases of the price level and replaces a prevision of future land prices that nobody can provide. The CIP-coefficient of 1.009 is in addition to landowner-specific coefficients of adaptation (table 7).

(31) 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.

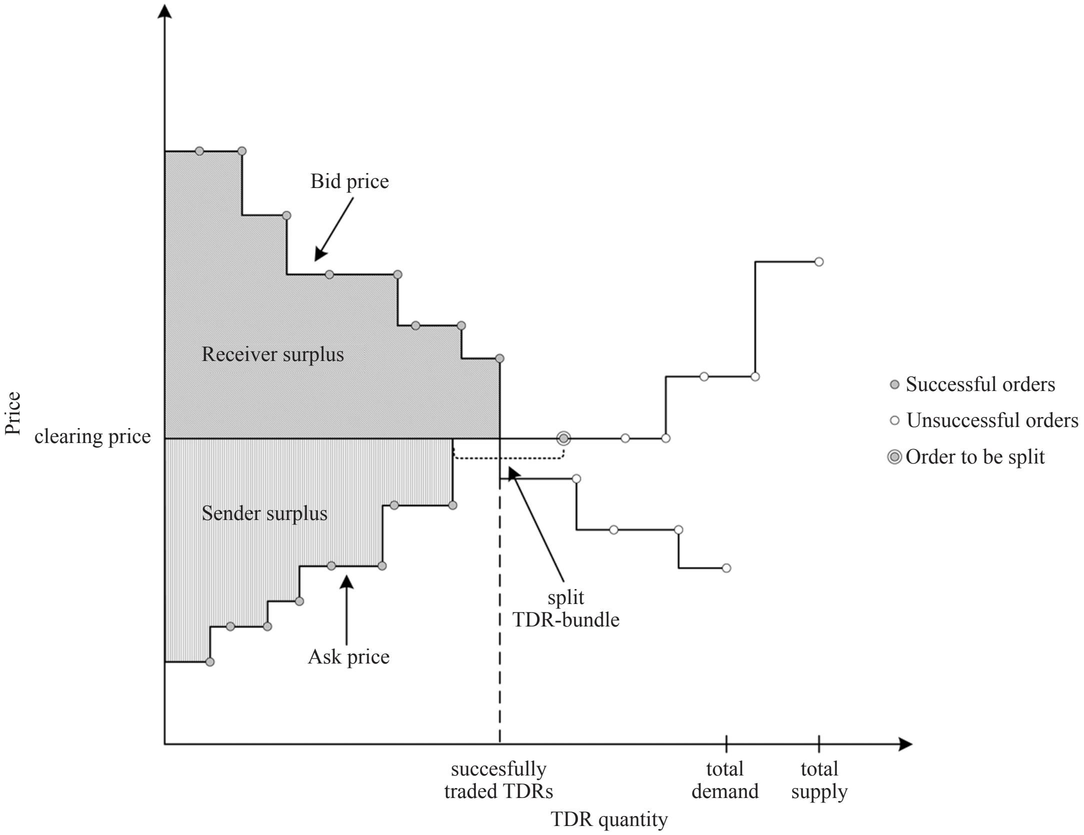

Figure 3. Calculation of the market clearing price (TDR—transferable development rights).

After each trading period, the trading agent informs the sender and receiver agents about their trading result (p_{clear} and q_{transfer}, see figure 2). The successful receiver agents all pay the same (uniform) market clearing price.

4 Results

In this section we present four different model settings (see table 8) matching our formulated research questions (see subsection 2.3), with the particular aim of calculating the resulting prices and traded quantities of TDR. Note that by 'rational behavior' we mean that the ask and bid prices are calculated in accordance with the theoretical TDR value [see equation (4)].

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 across all 100 random runs.

Table 8. Model settings with different parameters/variables referring to the research questions.

Model setting	Participation probability of sender and receiver agents	Behavior of sender and receiver agents	Research questions
1	according to the TDR survey	according to the TDR survey	1–4
2	according to the TDR survey	rational behavior	5
3	participation probability of 100%	rational behavior	5
4	participation probability according to the TDR survey is varied by +/−10% and +/−20%	according to the TDR survey	6

4.1 Results of setting 1

We present the results for Switzerland (see subsection 4.1.1) and specifically for the Canton of Valais (see subsection 4.1.2).

4.1.1 *Results for Switzerland*

Table 9 and figure 4 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 1165 CHF/TDR, leading to an overall transaction volume of 3.1 billion CHF. In the following 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 of building zone land in the sending area (36% of the total sending area) and to develop 7.4 km^2 of new building zone land in the receiving area (36% of the total receiving area).

Table 9. TDR market results for Switzerland (setting 1).

Auction number	TDR supply		TDR demand		TDR traded			Clearing price	Total volume
	sending area (km^2)	TDR quantity	receiving area (km^2)	TDR quantity	sending area (km^2)	receiving area (km^2)	TDR quantity	CHF/ TDR	millions 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	1 196[a]	4 012

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

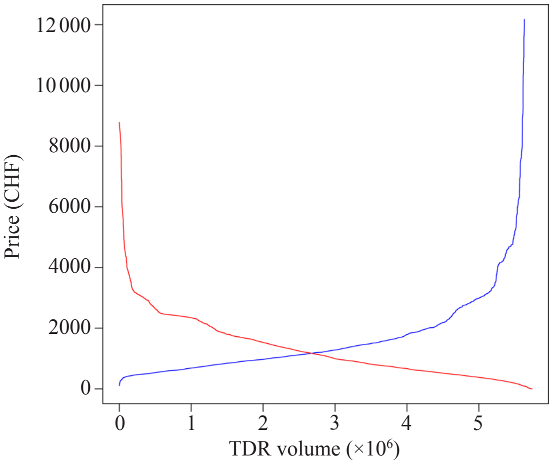

Figure 4. [In color online.] Supply (blue) and demand (red) for TDR+ in the first auction (setting 1).

4.1.2 *Results for the Canton of Valais*

Because of the extraordinarily high supply of undeveloped building zones and low demand for building zones in the Canton of Valais (for reasons see the calculated quotients of the sending and receiving area for the Canton of Valais in table A1) we analyze the impact of the TDR market here in detail. The model settings are the same as in subsection 4.1.1.

Table 10 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 10. TDR market results for the Canton of Valais (setting 1).

Auction number	TDR supply		TDR demand		TDR traded			Clearing price	Total volume
	sending area (km^2)	TDR quantity	receiving area (km^2)	TDR quantity	sending area (km^2)	receiving area (km^2)	TDR quantity	CHF/ TDR	millions CHF
1	6.18	1 478 357	0.00 [b]	1 025	3.19	0.00	838 697	1 165	977
2	2.99	639 660	0.00 [b]	1 025	0.30	0.00	72 715	1 221	89
3	2.69	566 945	0.00 [b]	1 025	0.05	0.00	9 564	1 269	12
4	2.64	557 381	0.00 [b]	1 025	0.25	0.00	47 156	1 345	63
5	2.39	510 225	0.00 [b]	1 025	0.20	0.00	40 612	1 423	58
All					3.99	0.00	1 008 744	1 196 [a]	1 199

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

[b] 4477 m^2.

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 subsection 4.1, however, with sender and receiver agents who ask, respectively, bid the theoretical TDR value. We present only the results of the first auction because it did not seem useful to assume hypothetical adaptation functions (32) for the successive four auctions.

The simulation shows that the traded TDR quantity increases where agents behave rationally (table 11 compared with table 9). It would be possible to downzone approximately 39% more land in the sending area and to develop approximately 39% more land in the

Table 11. TDR market results for Switzerland (setting 2).

Auction number	TDR supply		TDR demand		TDR traded			Clearing price	Total volume
	sending area (km^2)	TDR quantity	receiving area (km^2)	TDR quantity	sending area (km^2)	receiving area (km^2)	TDR quantity	CHF/ TDR	millions CHF
1	19.40	5 572 193	13.06	5 723 953	12.34	7.99	3 635 210	1 453	5 282

Note that the numbers in the first four columns (TDR supply and demand) are not exactly the same as in table 9 because of the randomly chosen agents when considering the agents' participation probabilities.

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(32) 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).

receiving area. However, the clearing price would also increase by approximately 25%. The overall financial transaction volume would be 5.3 billion CHF.

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 (eg, ask high prices in order to maximize the surplus) and therefore the supply and demand curves are not as steep.

4.3 Results of setting 3

To further investigate the impact of rational behavior in the first auction, we also simulated the TDR market with participation probabilities of 100%. The corresponding results are illustrated in table 12 and figure B1 (see appendix B). 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 1397 CHF/TDR can be interpreted as the 'theoretical' market clearing price.

Table 12. TDR market results for Switzerland (setting 3).

Auction number	TDR supply		TDR demand		TDR traded			Clearing price	Total volume
	sending area (km^2)	TDR quantity	receiving area (km^2)	TDR quantity	sending area (km^2)	receiving area (km^2)	TDR quantity	CHF/ TDR	millions 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 Results of setting 4

In order to take into account the uncertainties in the estimation of the participation probability parameters p_{send} and p_{receive}, we increased/decreased these parameters by 10% and 20%, respectively, 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.

Figure 5 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 in a 'typical' market, the clearing price increases with increased participation on the demand side and 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 (see matrix diagonal in figure 5).

As expected, with increased participation probabilities the sold TDR quantity also increases. 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. Additional figures on the effect on the clearing price and the TDR quantity sold over five auctions are provided in the appendix (figures B2–B5).

	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

Figure 5. 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.

5 Discussion

The results showed that the 'rationality' (see definition in section 4) of the agents regarding their participation and their offer 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(33) and indicated that the model produced realistic outcomes. This comparison of prices resulting from the simulation and market prices is one validation of our model. We have resorted to this form of validation, as validating ABMs 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 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 (eg, see Pruetz, 2003) and by the fact that in a 'real' implementation of a TDR market the willingness to participate might be higher because of

(33) 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 AG (2011) current prices for Switzerland are in the range of 1150 to 1600 CHF/m^2. This value has been calculated by dividing the building zone prices [average price for residential zone (single- and multiple-family houses)] by realistic average utilization factors (eg, 0.25 to 0.35) (see definition of TDR quantity per parcel in subsection 3.3).

better information through the use of additional diffusion or communication instruments, or through self-diffusion effects (eg, see 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.(34)

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 the behavior of other agents in the 'neighborhood'. However, in economics—in contrast to psychology—there is 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.(35) The survey and use of empirical land data is also the reason for limiting the modeled auctions at five. With this data, modeling more auctions would not have led to reasonable results, and modeling more auctions with other data—forcibly much less realistic—would have conflicted with the aim of the project to develop a model producing reliable data for the political debate.

Moreover, it should be noted that the TDR survey did not consider the opportunity costs (36) of both senders and receivers, and therefore these costs are ignored in the simulation as well.

One recurring objection is the uniform market price of the auction. Uniformity is intended to some degree so as to direct development into areas with high utility, and some heterogeneity is evened out by planning decisions regarding sending and receiving areas (eg, land with good public transport may become a receiver area and such land may not be included in a sender zone). At the same time, some heterogeneity of land values is reflected. The number of TDR to be assigned is based on the utilization factor which reflects the neighboring settlements, and the price for land may vary in practice.

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) seem to be the most adequate: (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. 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: that is, flows from urban areas to rural areas in those places where the authorities did not follow the Swiss planning rules and hence are now disposing of overly large building zones.

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(34) A more detailed sensitivity analysis of the parameters p_{send} and p_{receive} can be found in Menghini (2013).

(35) For more information about behavior models with learning processes see, for example, Brenner (2006) and Duffy (2006).

(36) 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.

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 (eg, minimum 20%, 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 downzoning of a parcel (eg, in the form of a compensation fund) because the tax would be levied only when the parcel is sold or developed following the proposed national law.

In the TDR–ABM we did not consider the recently adopted(37) '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 to those in the Canton of Zurich, and (b) the exact implementation as a law is currently still under way.

6 Conclusions

The main contributions of our proposal in relation to previous work on TDR in Switzerland (see, for example, 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 ABM 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 1165 to 1453 CHF/TDR. The TDR prices were all comparable with current land prices in Switzerland (market prices). The overall money transaction volume would be approximately 4 billion 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 of building zone land in the sending area(38) and the development of 7.4 km^2 new building zone land in the receiving area 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 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) 1453 CHF/TDR with participation probabilities according to the TDR survey and (b) to 1376 CHF/TDR with participation probabilities of 100%. In (a) the traded TDR quantity in the first auction would be 3.6 billion TDR, and in (b) 5.9 billion TDR. (6) The TDR market price remained quite stable when both sender and receiver participation

(37) Adopted on 17 June 2012. For more information see: http://www.zh.ch/internet/de/aktuell/news/medienmitteilungen/2012/185_kulturlandinitiative.html

(38) 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).

probabilities changed at 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).

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Appendix A. Characteristics of the sending and receiving area

Table A1. Characteristics (canton level) of the sending and receiving areas for the year 2018 [own calculations, data basis: ARE (2008) and Fahrländer Partner AG (2008)].

Canton	Sending area		Receiving area		Quotient of sending and receiving area	
	area (km^2)	assigned TDR[a] quantity	area (km^2)	assigned TDR quantity	area	TDR
Zürich	1.58	640 082	5.23	2 751 866	0.30	0.23
Bern / Berne	0.76	231 376	4.33	1 761 932	0.18	0.13
Luzern	0.86	299 286	0.51	262 332	1.69	1.14
Uri	0.06	18 242	0.08	31 999	0.75	0.57
Schwyz	0.14	55 412	0.65	266 763	0.22	0.21
Obwalden	0.07	24 970	0.00	834	na	29.94
Nidwalden	0.08	29 678	0.23	89 660	0.35	0.33
Glarus	0.00	0	0.02	8 468	na	na
Zug	0.12	62 131	0.32	131 434	0.38	0.47
Fribourg/Freiburg	2.71	702 542	0.28	106 360	9.68	6.61
Solothurn	1.56	487 791	0.02	6 728	78.00	72.50
Basel-Stadt	0.01	4 468	0.30	221 568	0.03	0.02
Basel-Landschaft	0.55	190 230	1.10	454 228	0.50	0.42
Schaffhausen	0.24	85 578	0.13	53 659	1.85	1.59
Appenzell Ausserrhoden	0.05	14 842	0.12	40 559	0.42	0.37
Appenzell Innerrhoden	0.03	8 335	0.06	22 948	0.50	0.36
St. Gallen	0.85	261 362	0.50	167 716	1.70	1.56
Graubünden/Grigioni/Grischun	1.18	408 396	0.10	39 864	11.80	10.24
Aargau	1.84	631 325	1.45	577 612	1.27	1.09
Thurgau	1.11	360 562	0.04	12 733	27.75	28.32
Ticino	2.63	942 180	0.32	130 161	8.22	7.24
Vaud	4.82	1 157 783	2.35	961 932	2.05	1.20
Valais / Wallis	9.41	2 249 384	0.01	1 545	941.00	1455.91
Neuchâtel	0.60	165 286	0.41	179 867	1.46	0.92
Genève	0.13	38 691	1.92	749 169	0.07	0.05
Jura	0.49	105 012	0.01	2 411	49.00	43.56
Overall (whole Switzerland)	31.88	9 174 943	20.49	9 034 348	1.56	1.02

[a] TDR—transferable development rights.
na—not applicable.

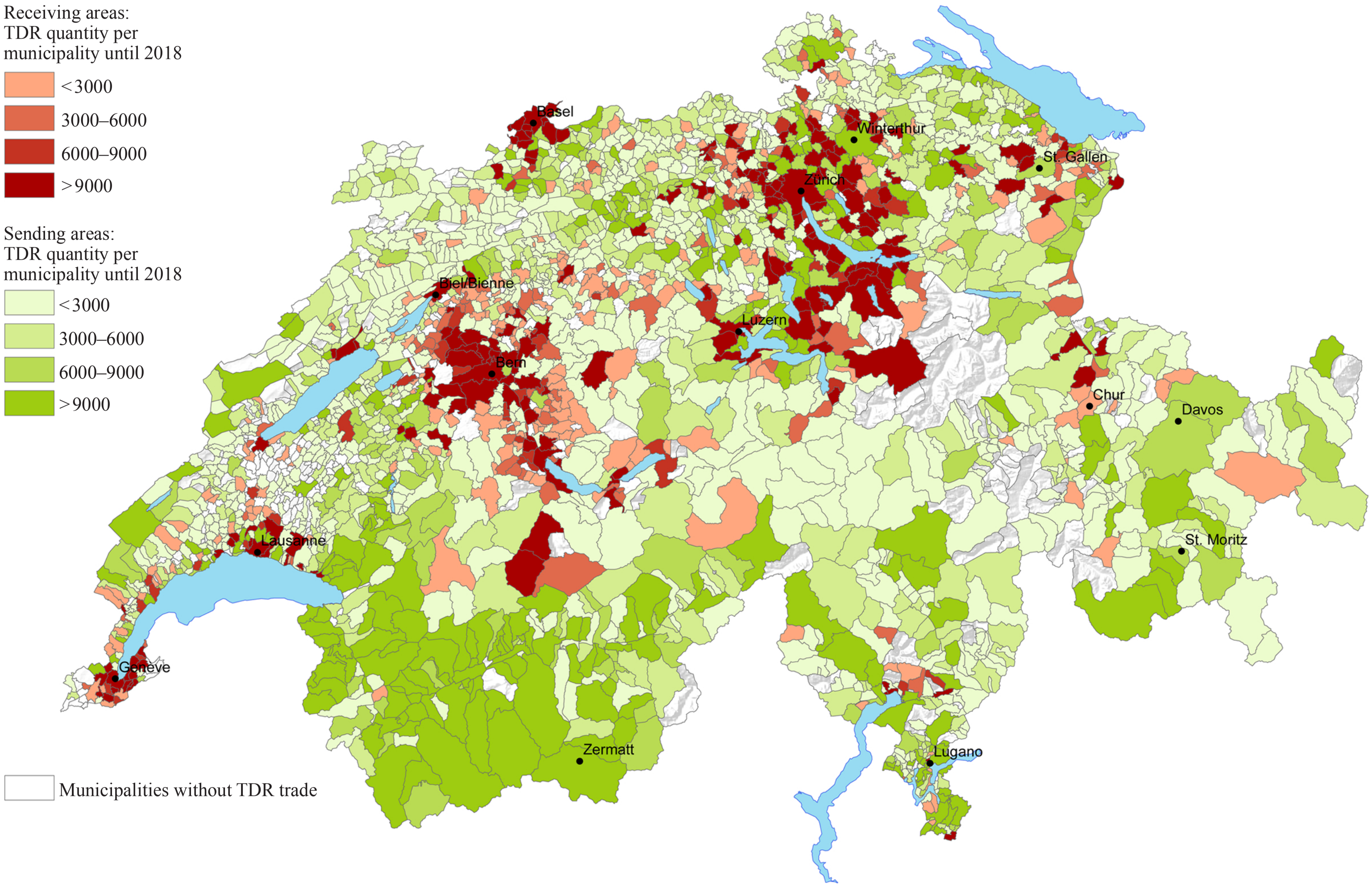


Figure A1. [In color online.] Spatial distribution of sending and receiving areas in Switzerland.

Appendix B
Additional results of setting 3

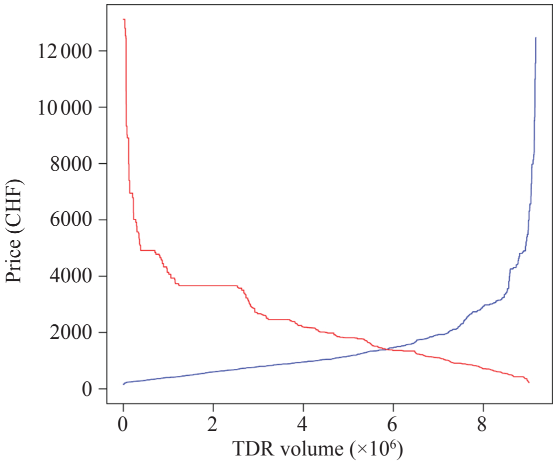
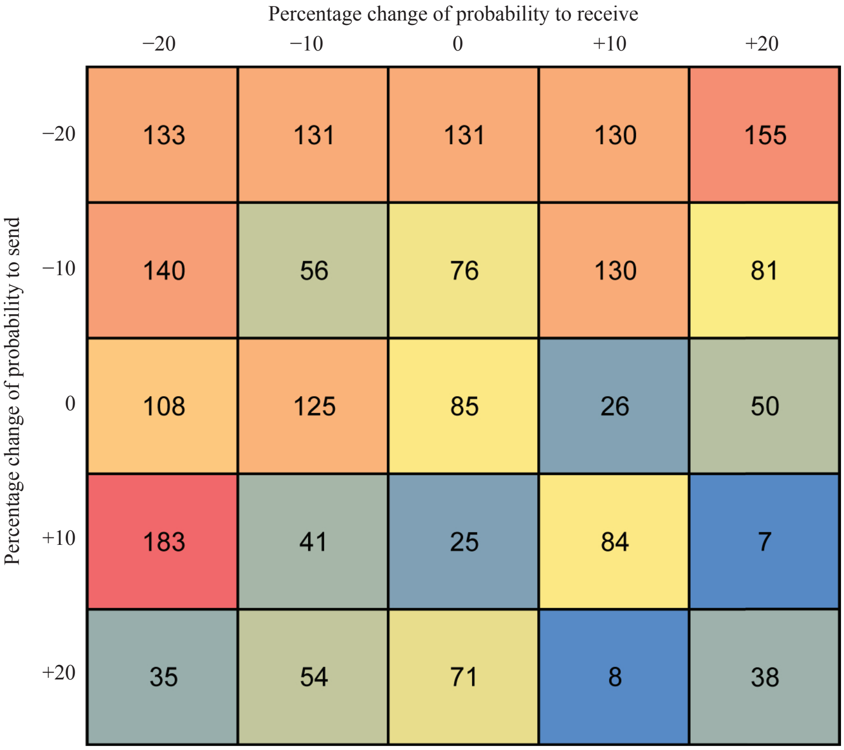


Figure B1. [In color online.] Supply (blue) and demand (red) for TDR (transferable development rights) in the first auction (setting 3).

Additional results of setting 4

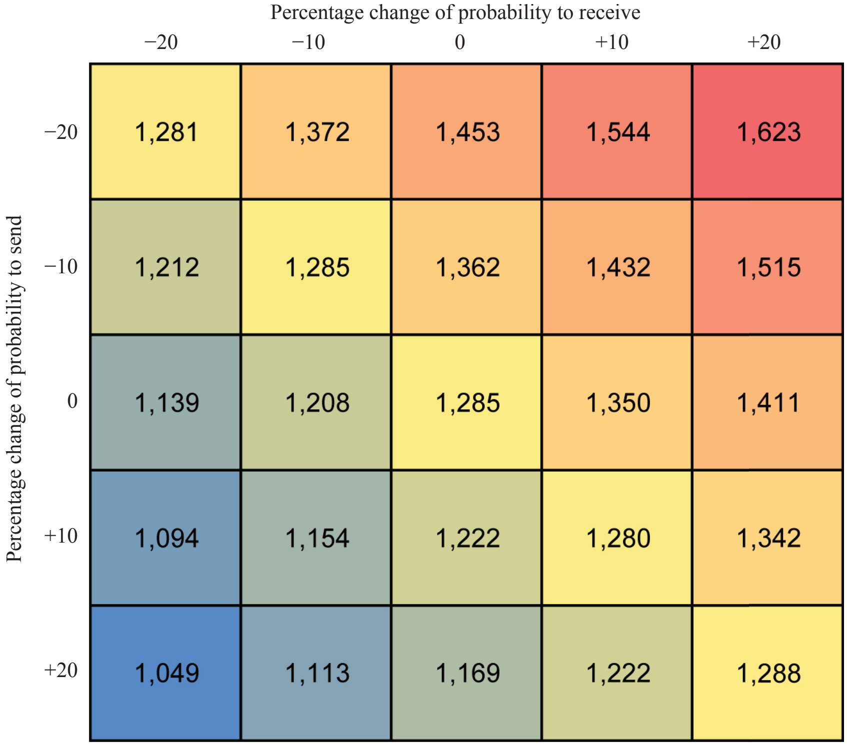


Percentage change of probability to receive

Percentage change of probability to send

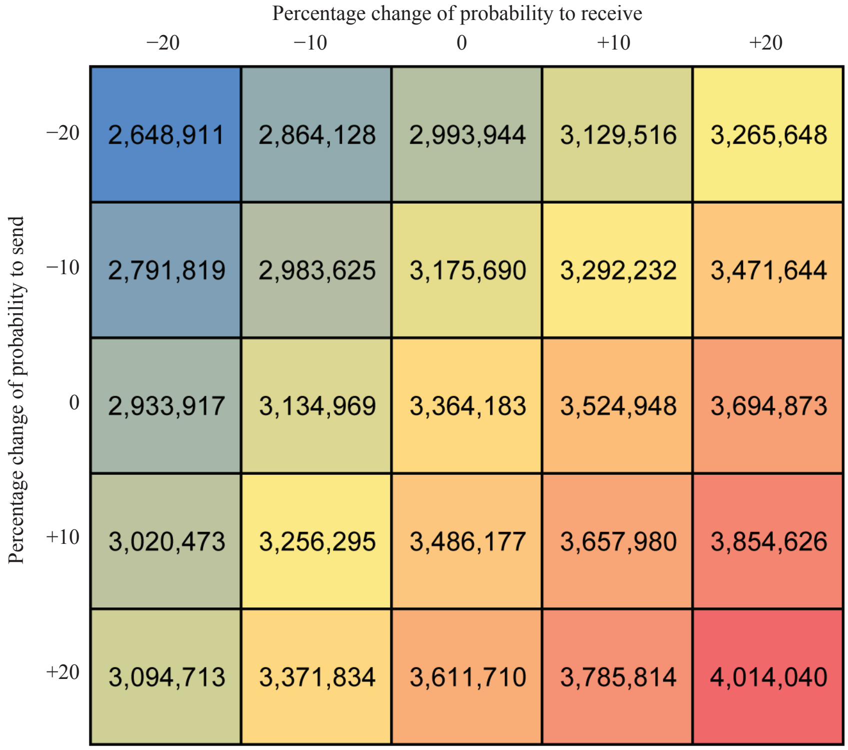
	−20	−10	0	+10	+20
−20	133	131	131	130	155
−10	140	56	76	130	81
0	108	125	85	26	50
+10	183	41	25	84	7
+20	35	54	71	8	38

Figure B2. [In color online.] Effect of percentage change of parameters p_{send} and p_{receive} on the variance of the clearing price in the first auction.



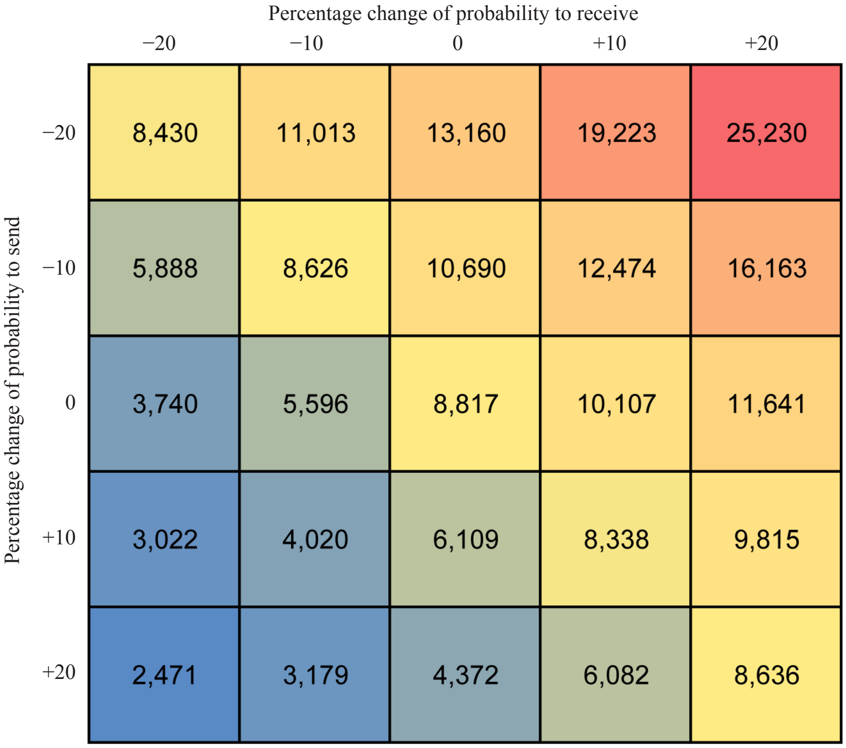
	−20	−10	0	+10	+20
−20	1,281	1,372	1,453	1,544	1,623
−10	1,212	1,285	1,362	1,432	1,515
0	1,139	1,208	1,285	1,350	1,411
+10	1,094	1,154	1,222	1,280	1,342
+20	1,049	1,113	1,169	1,222	1,288

Figure B3. [In color online.] Effect of percentage change of parameters p_{send} and p_{receive} on the average clearing price over five 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

Figure B4. [In color online.] Effect of percentage change of parameters p_{send} and p_{receive} on the TDR (transferable development rights) quantity sold in the five auctions.



Percentage change of probability to receive

Percentage change of probability to send

	−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

Figure B5. [In color online.] Effect of percentage change of parameters p_{send} and p_{receive} on the variance of the clearing price over five auctions.