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Pipes, Taps and Vendors: Managing and Regulating the Unconnected Water Market

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Pipes, Taps and Vendors: Managing and Regulating the Unconnected Water Market

by
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Christian von Hirschhausen.

January 31, 2018

Against the background of the human rights to water and the SDG No. 6, vendors play a pivotal role for an IWRM-based water supply system in the future. With the help of a micro-economic model, an optimal modal split is derived, the result of which is that not all households should be served by the pipe-based municipal supply. Instead, the non-connected households should be served by non-mobile or mobile vendors. Furthermore, we analyze different structures in the unconnected market. If vendors compete against each other, the optimal modal split can be replicated. If vendors form a cartel, market interventions, such as a cost related zonal price cap or a subsidizing strategy, are required for preventing the abuse of market power by the vendors.

JEL: L11 (Production, Pricing, and Market Structure); L51 (Economics of Regulation), Q25 (Water); R12 (Size and Spatial Distributions of Regional Economic Activity)

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1 Introduction

In 2010, the human rights to water was established, which ensures the universal access to safe, clean and affordable drinking water (UN, 2010). Despite progresses in reaching the human right also under the background of the Millenium Development Goals (MDGs), about 663 million people worldwide in the year 2015 still used unimproved drinking water sources and therefore did not have access to an adequate water supply. Nearly half of these people live in Sub-Saharan Africa, while about one-fifth live in South Asia (UN, 2015b). The Millenium Development Goals were followed by the Sustainable Development Goals (SDGs) which were adopted by the UN General Assembly on 25 September 2015 (UNDP, 2015). The target No. 6.1 of the SDGs postulates the "universal and equitable access to safe and affordable drinking water" for all humans by 2030 (UN, 2015a). For reaching this universal and challenging goal, the informal economy may play an important role.

In squatter settlements, shanytowns, slums and even rural areas, the informal economy provides the poor, which are not served by the respective municipality, with an alternative avenue for urban services, such as water, sanitation, transportation and trash-collection (Soto (1989); Whittington et al. (1991); Njiru (2004); Roy (2005); Opryszko et al. (2009); Ishaku et al. (2010); Olajuyigbe et al. (2012); Onyenechere et al. (2012); Ayalew et al. (2014); Fox (2014); Mehta et al. (2014); Wutich et al. (2016)). Therefore, the informal economy (e.g. informal water supply) bridges the gap between urban services delivered by municipalities and those needed (Portes and Haller (2010); Wutich et al. (2016)).

Water vendors play an important role in the informal water supply, because they serve those people with water that are not connected to the public water supply. Zaroff and Okun (1984), Lovei and Whittington (1993), Snell and Mundial (1998), Njiru (2004), Kjellén and McGranahan (2006), Sansom and Bos (2008), Opryszko et al. (2009), Wutich et al. (2014) and Wutich et al. (2016) focus on definitions, conceptions as well as operation modes of water vendors from different perspectives. Water vendors usually deliver water to the home of the poor by using hand-carried donkey carts or trucks (mobile vendors) or they operate reselling stations from where consumers can collect the water (water kiosks).

Despite the essential importance of the informal water supply, there are also some disadvantages related with water vending compared to the public water supply. For instance, water from vendors is in some cases the reason for serious water-related diseases, because of the low quality of vended water compared to municipal water (Whittington et al. (1989); Zaroff and Okun (1984); Kjellén and McGranahan (2006); Olajuyigbe et al. (2012); Hutin et al. (2003)).[1] Furthermore, vended water is often more expensive than municipal water from the public water supply (Crane (1994); Snell and Mundial (1998); Collignon (1999); Kjellén (2000); Solo (2003); Kariuki and Schwartz (2005); Opryszko et al. (2009); Ishaku et al. (2010); Bayliss

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[1] However, a few studies, such as Collignon and Vézina (2000) or Solo (1999), state that vended water is comparable or better than water from other local sources.

and Tukai (2011); Olajuyigbe et al. (2012); Dauda et al. (2015); Rahaman and Ahmed (2016)).[2] According to Kjellén and McGranahan (2006), these high prices may result from the abuse of market power by the water vendors. However, other studies, like Whittington et al. (1991), Solo (1999), Collignon and Vézina (2000), Kariuki and Schwartz (2005) and Opryszko et al. (2009), justify a higher price level for vended water than for municipal water due to higher specific investment and operation costs. Therefore, the profits of vendors are at a moderate level, even the high prices for vended water. The investment, operation and unit costs for selected water vendors in selected regions are presented by for instance by Lovei and Whittington (1993), Collignon and Vézina (2000), Al-Hamdi and Alaerts (2000), Kayaga and Franceys (2007) and Keener et al. (2009). Studies such as Al-Hamdi and Alaerts (2000) compare the unit costs of vended water with those of municipal water, which illustrates the cost advantage of the public water supply. Of course, the unit cost level depends not only on the used technology and operation mode, but also on the amount of supply; therefore Nauges and Van den Berg (2008) analyzes the size of economies of scale and scope for the public water supply in selected regions. Beside the accounting costs, there are opportunity costs, which result from, for instance, hauling activities, that should be addressed. Whittington et al. (1990) estimates these hauling costs for various scenarios.

This paper contributes to the discussion by identifying the main drivers of what we call the “optimal modal split” between water supply through larger networks, and the self-provisioning of water through vendors or – most often for poverty reasons – an undersupply of clean water after all. The general opinion is that connected water supply should be the ultimate objective of a developed system, whereas there may be economic reasons to believe that a certain degree of unconnected water supply may be economic for a certain class of users, in particular the sub-urban poor. Therefore, similar to argumentation done by McGranahan et al. (2006), Chaudhury (2013) as well as Wutich et al. (2016), water vending is a necessary path to achieve the ambitious political goals formulated by the human rights for water and the SDG No. 6.

The paper applies a microeconomic-based stylized model to derive the potential impact of external and internal factors, such as cost structures, on the development of the system. We assume a linear city, with some plausible assumptions on income and willingness-to-pay, and then calculate the “optimal” tap density, leading in turn to an optimal modal split between piped water consumption, and unconnected water consumption. We also address issues going beyond the simple competitive market model, such as strategic behavior by water vendors.

The paper is structured in the following way: The next section sets the scene, by discussing the main levers of water supply in a developing context, and by deriving a model setting that represents a broad range of water supply issues identified on the ground. Section 3 then provides the basic model of the “linear city” of water

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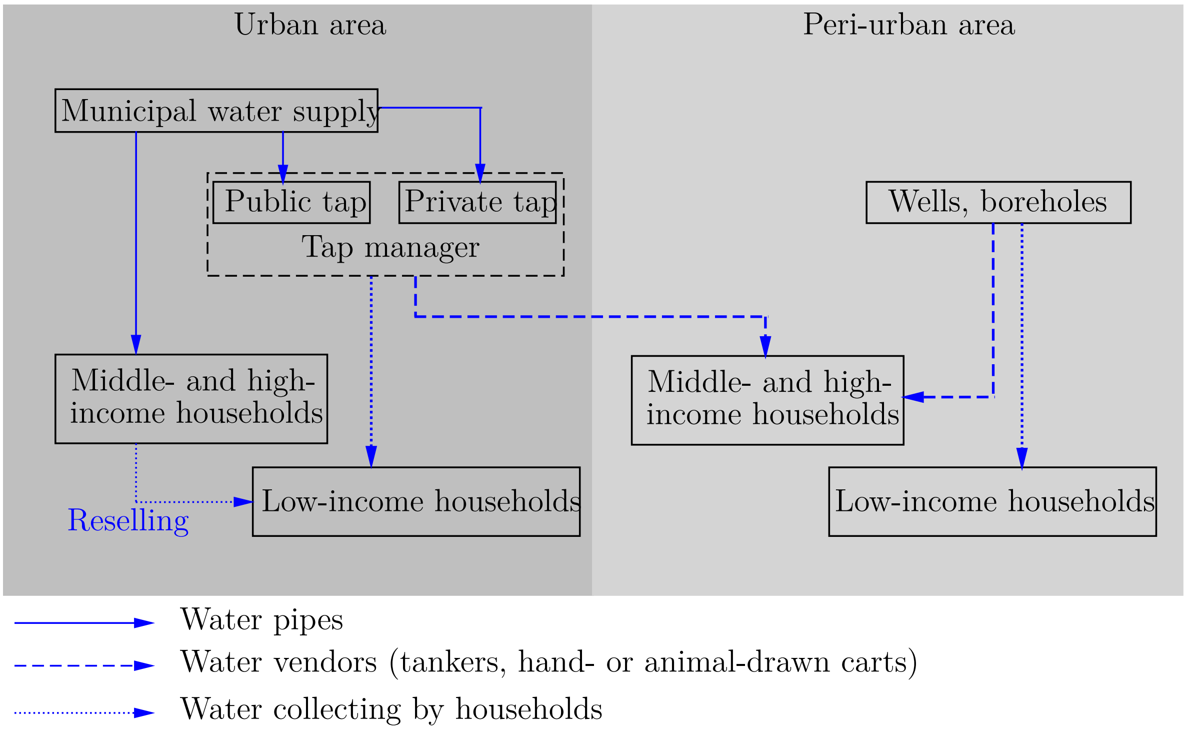
[2] According to Wutich et al. (2016), the costs for vended water range from 4 to 30 times the cost of municipal water.



Source: Own illustration based on Kjellén and McGranahan (2006).

Figure 2.1: Decentralized water sector in urban and peri-urban areas

supply, and the main assumptions on costs, willingness-to-pay, and other variables. Tap density is the key parameter at the discretion of the water utility, and we derive the total costs of connected water consumption as a function of the number of taps. Section 3.2 then contains the derivation of the optimal modal split, by maximizing the social benefit of connected and unconnected water supply, other variables derived from the linear city, e.g. the connected households, the distance between the taps, and the action of the vendors; we also discuss potential deviations from this optimum, when taking into account “non-economic” aspects such as the human right to water. Section 4 then introduces a further complication of the previous setting, with a fully competitive vendors market: the (disillusioning) case in which vendors are not working under competition (and towards social welfare), but act strategically by building cartels amongst them. Section 5 concludes.

2 Institutional and Technical Setting

Beside the municipal water supply, water vendors play an important role in the water supply system especially for those households which are not connected to the municipal water supply.

In this introduction, we set the scene for the analysis of water supply by discussing the basic elements of a model of optimal modal split between centralized, municipal, grid-based supply by a water utility, the supply by mobile water vendors and the self-provisioning, e.g. through boreholes or water kiosks. Figure (2.1) depicts a possible model setting from which one has to choose. Assume a water utility in some urban center in an emerging or developing country, which provides municipal water to its fairly wealthy constituency in the core of the city. This water utility can operate as a non-profit, welfare-oriented actor pursuing goals of integrated water resource management (IWRM), or it can be considered as a profit-maximizing agent. Different forms of organization are possible for the municipal water supply. For instance, it can be operated by a private or a community-based company. (Kariuki and Schwartz, 2005) Depending on the goal of the municipal water supplier, the utility will strive to provide access to the periurban region as long as it serves its goals.[3] Residual households which are not connected to the municipal water supply grid have the both options: either to supply themselves with water from wells, boreholes, surface water bodies etc. where access is free or to purchase water from water vendors. Self-supply especially in regions with non-adequate sanitation services is related with a high risk of diseases, hence for those cases it is not a adequate form of water supply claimed by the human rights to water and the Sustainable Development Goals. However, if water in the free accessible boreholes, wells, surface water body is clean and safe, the self-supply can be seen as an adequate option of supply. With respect to vendors, it is possible to distinct between the non-mobile and mobile vendors. (Kariuki and Schwartz, 2005). The non-mobile vendors can be public-owned standpipes or taps, private-owned water kiosks or households with an access to the public water supply which resell the provided,municipal water to the consumers with no access to public water supply (informal standpipe). Mobile vendors procure water at a connected tap, and transport it to more remote areas, most often by hand- or motorcycles-drawn carts, tankers etc. These water vendors can be modeled in different ways: they may be in competition with each other, thus providing water at incremental costs, or they are cartelized or monopolistic; in that case, they will exploit the consumers' willingness-to-pay, and perhaps exclude some people from satisfying their most fundamental water needs.

3 The Model

In the following we want to set up an analytical framework in a model type one can find in spatial economics: the linear city. [4] It is assumed that all water customers are arranged along a line, the linear city. The customer density is constant along the

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[3] If the municipal water supplier is welfare-oriented, the utility will provide access to the periurban region as long it make sense from a social welfare perspective. However if the municipal supplier is profit-oriented, it will provide access in the periurban region as long as it can increases its profits.

[4] The linear city model dates back to Harold Hotelling who dealt with spatial competition. Meanwhile it is an integral part of industrial economics, see e.g. Tirole (1988) as well as Fujita et al. (1999). These model have been further developed by Salop (1979) who analyzed incomplete competition in the space with the help of a circular city.

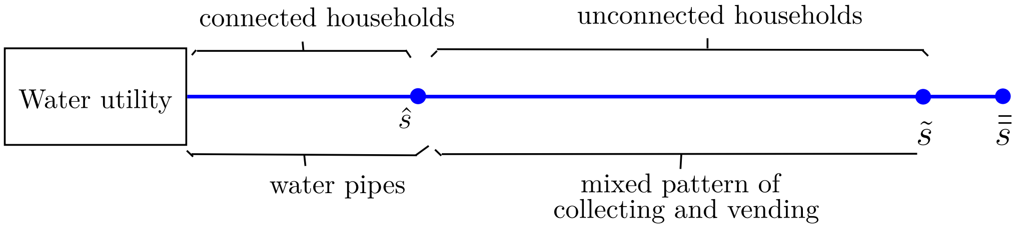

Figure 3.1: Linear city

line (identical distribution). All customers demand just one unit of water, say 1 m^3 per month. The willingness to pay $V(s) = a - bs$ is decreasing everywhere along the linear city from the left to the right side. This property stems from the assumption that income of households decreases from left to right. On the left, the high incomes live, followed by the middle class and finally the poor ones, which settle on the right side. This model structure is somewhat artificial, but it makes the analysis more lucid and allows to identify the economic drivers that determine the water supply mode in the space Figure (3.1) shows the spatial structure, i.e. the structure of the various modes of water supply what we call the modal split.. In this respect we follow a discrete choice approach as applied by Whittington et al. (1990) where only the household decision for the supply mode is modeled. The demand function of water is not taken into account.

The water utility is located to the left.[5] It conveys water to the connected households up to $\hat{s}$. We assume that household's income decrease from left to right. The poor are located on the right side of the figure. Between $\hat{s}$ and $\tilde{s}$ the water supply is based on accessible taps and the service of water vendors. Both, customers in the vicinity of the taps and water vendors can receive water from the water kiosks placed in this interval. Subsequently, we will derive the precise structure of the unconnected water supply, i.e. we will derive where the segments for water collecting by customers and the segments of water supply by vendors are located. The stretch between $\tilde{s}$ and $\bar{\bar{s}}$ represents the very outskirt of the linear city that might be not supplied by water. In this segment we have a supply situation that contradicts the UN directives and we have to ask ourselves how to close this gap (see below).

The simple model does not include other sources, e.g. water wells, boreholes or the collection of surface water. Also, we do not consider illegal tapping. However, despite the simplicity we can derive some insightful results. Let us proceed by defining the costs of the various actors of the linear city.

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[5] The model of the linear city can be extended arbitrarily. The waterworks can also be located in the centre of the city with a right and left water pipe. Star-shaped distribution branches can also be arranged in all directions.

3.1 Cost structures

Roughly, the water utility incurs two cost components. The water supply costs depend on the total amount of water provided and the capacity of the transportation and distribution system. From empirical studies we know that the cost structure of water utilities varies considerably, as indicated by different estimated measures of density, scale and scope economies differ considerably.[6] We assume in the following that the water utility displays (weak) diseconomies of scale. Increasing the volume of water produced, the number of connections to be served, and the network length by a factor $\lambda > 1$ leads to an increase in costs greater than λ. This is due to the assumption that further down along the city's geographical line the expansion of household connection gets more expensive on the margin due to deficiencies of the complementary infrastructure of city areas where people with lower income live (streets, house foundations, etc.). The deteriorating quality of this infrastructure allows the assumption of weak diseconomies.

Hence, total costs of total water supply and household connections are specified as

$$C_{WU} = m\tilde{s} + k\hat{s} + \frac{\kappa}{2}\hat{s}^2 \tag{3.1}$$

where $m\tilde{s}$ are the costs of water treatment. The parameters k and κ determine the costs of household connections along the city line displaying increasing incremental costs. These costs include the costs of the water mains and the branch line connections. Note that the sole dependence of the cost function on the area served, i.e. the stretch s, is the result of the assumption that all customers along the line consume the same amount of water, say, 1 m^3: Collecting water is rather cumbersome. Often it is the women who bring water with the help of canisters. The costs relate not only to the purchase price, but also to the lost time[7], which is missing for other productive activities. These opportunity costs have to be taken into account in the supply cost function.

Figure (3.2) shows the cost structure of the line segment between $\hat{s}$ and $\tilde{s}$. In this area, customers collect water from kiosks or are supplied by vendors. Take, for example, the location of tap 2. A customer located at point A' incurs costs A to collect 1 m^3 of water from tap 2. Mathematically, these costs are

$$D = \delta_2 + \delta_1 s, \quad \text{where} \quad s = A' \tag{3.2}$$

δ_2 are the time costs of filling water into a canister of a capacity of , say, 1 m^3. These costs do not depend on the distance between the tap and the household. δ_2 are monetarized time costs to haul $1m^3$, say, 100 meter[8]. If the household is located at A' hauling costs are $\delta_1 A'$ Hence, total collecting costs of all customers in the vicinity of taps up to A' are:

$$D_F = \delta_2 \int_0^{A'} ds + \delta_1 \int_0^{A'} sds = \delta_2 A' + \frac{\delta_1}{2}(A')^2 \tag{3.3}$$

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[6] See Nauges and Van den Berg (2008).

[7] For estimations see Whittington et al. (1990).

[8] In this case s is measured in units of 100 meters.

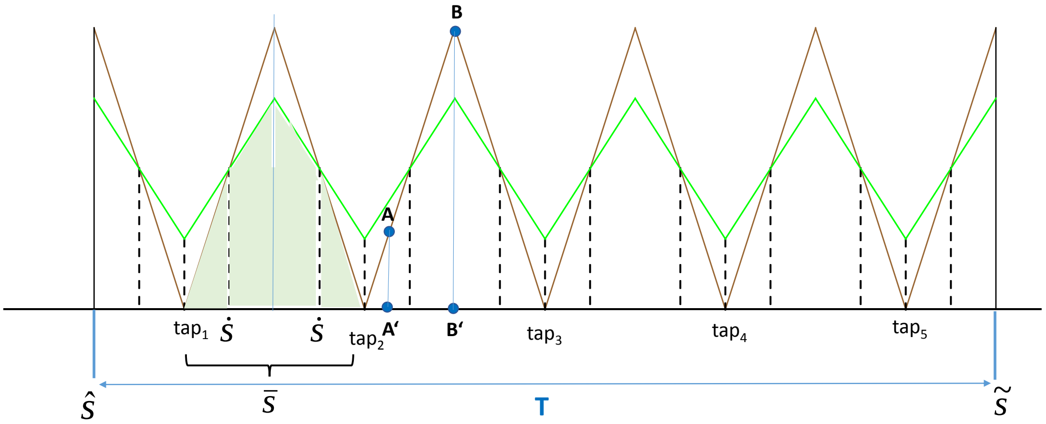

Figure 3.2: Tap density

In the following we assume without loss of generality that $\delta_2 = 0$

Customers at point B' incur collecting costs in the height[9] of $B = \delta B'$. Furthermore, customers at B' are indifferent whether to collect water from tap 2 or tap 3 provided the water prices charged at tap 2 and tap 3 are equal. Thus, point B is the gravitational threshold which divides the catchment areas of tap 2 and tap 3 if only water collecting is possible. However, in our model customers can choose between water collecting and water provision by vendors and the task remains to find the optimal split between both modes. Optimality refers to a supply structure that minimizes the costs. To do so, we have to derive the cost structure of vendors. Thereby, we have to distinguish between an supply structure with many vendors and few large ones (or one large one). We begin with the case of many small vendors.

Vendors' costs are twofold.[10] There is the time loss that incurs when filling cans at the kiosk. The same applies to the selling costs, which come from the lost time of selling the water to customers, i.e. decanting water into the jerrycans of customers. If we weight this amount of time with the income per hours attainable in other occupations (opportunity costs) we can derive the first cost component c_2. This component contains both cantation and decantation We also can include capacity costs of the small cart the vendor is pulling. Therefore, we assume $c_2 > \delta_2$. In addition to these opportunity costs, vendors also face hauling costs. These hauling costs are less per $1m^3$ than hauling costs of collectors, because vendors use

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[9] We have droped the subscript, i.e. $\delta = \delta_2$

[10] We follow the analysis of Lovei and Whittington (1993) to develop the cost function of small vendors.

a technology which makes them quicker. Hence, hauling costs of vendors are less per m^3.

To summarize, total supply costs of a vendor supplying a customer at A' with 1 m^3 amount to

$$c_2 + c_1 A' \tag{3.4}$$

Thereby, it is assumed that $\delta_1 > c_1$ and $c_2 > \delta_2$ which implies that the vendor's marginal hauling costs will rise less quickly than the corresponding marginal costs of the collector. Both marginal cost functions intersect at $\dot{s}$ implying that customers to the right of $\dot{s}$ incur less costs if served by a vendor instead of collecting the water from the tap. Total costs to supply all customers from $\dot{s}$ to B' are

$$C_V = c_1 \int_{\dot{s}}^{B'} s ds + c_2 \int_{\dot{s}}^{B'} ds = \frac{c_1}{2}\left[(B')^2 - (\dot{s})^2\right] + c_2(B' - \dot{s}) \tag{3.5}$$

If customers are supplied by one large vendor the cost structure is different due to economies of scale. Large vendor operate with big trailers pulled by , e.g., donkey or with trucks. Due to the high capacity they have not to return to the tap to refill. Hence the costs structure is linear:

$$C_V = c_1^s \int_{\dot{s}}^{B'} ds + c_2^s \int_{\dot{s}}^{B'} ds = c_1^s(B' - \dot{s}) + c_2^s(B' - \dot{s}) \tag{3.6}$$

where $c_1^s > c_2$ are filling and capacity costs per $1m^3$ and $c_1^s < c_1$ are hauling costs per $1m^3$. In the following we only consider the case of many vendors. All our results apply also to the case of few or one large suppliers[11].

After all cost functions of the various supply modes have been defined and specified, the optimal supply structure of the water supply can be derived.

3.2 The Optimal Modal Split

The optimal modal split can be derived with the help of the IWRM approach. How far should the pipe-born water supply be extended, how many customers should ideally fetch water from the tap and what distance should water vendors cover? Finally, how many kiosks should optimally be installed along the line of the linear city. Deviding this task into two steps we begin with determining the optimal number of kiosks in a given uni-dimensional area T (see again Figure (3.2)) where customers are evenly distributed. To the left of the interval there are other customers that are connected to the water distribution system and beyond the right border there are either customers not integrated in water supply system or the border represents the city boundary. Since taps can be accessed from two sides it is optimal not to position the kiosks at the borders, but rather inwards. It remains to determine the optimal number of kiosks, the optimal distance and the areas in which the vendors operate.

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[11] Our model can be extended by including both, small vendors and large vendors.

This task can be accomplished by solving the following minimization program:

$$\min_{\dot{s},\bar{s},n}\left[n\left\{2[\frac{\delta}{2}\dot{s}^2+\frac{c_1}{2}[(\frac{\bar{s}}{2})^2-\dot{s}^2]+c_2((\frac{\bar{s}}{2})-\dot{s})]\right\}+rn\bar{s}+\rho n\right] \tag{3.7}$$

$$\begin{aligned} &\text{s.t.}\\ n\bar{s} &= T\\ \dot{s} &\leq (\bar{s}/2)\end{aligned}$$

where n is the number of taps and $\bar{s}$ is the distance between two taps. $\dot{s}$ indicates the width of the collecting segment and $2(\bar{s}-\dot{s})$ is the area vendors supply. r denotes the utilities water distribution costs per m^3 delivered[12] and ρ are the set-up and maintenance costs per kiosks which are independent of the amount of water supplied. From the Kuhn-Tucker-conditions we can derive[13] the optimal collecting range and the optimal vendor service area, the optimal distance between two taps and the optimal number of taps[14].

$$\dot{s}=\frac{c_2}{\delta-c_1} \qquad \frac{\bar{s}}{2}=\sqrt{\frac{1}{c_1}(\rho-c_2\dot{s})}=\sqrt{\frac{\rho(\delta-c_1)-c_2^2}{(\delta-c_1)c_1}} \tag{3.8}$$

The optimal collecting range can be explained with the help of Figure (3.2). The collecting costs for customers in the stretch $[0,\dot{s})$ are lower than the costs of being supplied by vendors. This turns around at $\dot{s}$ where vending costs are lower than water fetching costs. The optimal distance between two taps depends positively on the set-up costs ρ and negatively on δ, the slope of marginal collecting costs. The more expensive collecting is the higher the density of taps and vice versa[15].

Having optimized the structure of the tap density and vending areas we are now able to derive the cost function of this mixed supply line with respect to its length. Inserting the optimal values of $\dot{s}$ and $\bar{s}$ into Equation (3.7) yields[16]

$$C_{tv}=\left[c_1\frac{\bar{s}}{2}+c_2+r\right]T \quad = \quad c_{tv}T \tag{3.9}$$

where T indicates the length of that line.

It remains to determine the optimal modal split between the range of the area of connected households and the area of customers supplied by the mixed structure of taps and vendors. This can be achieved by the following program:

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[12] The term $rn\bar{s}$ is an abbreviation for $rn\bar{s}\bar{w}$, where $\bar{w}=1m^3$ and $\bar{s}\bar{w}$ is total water supplied at each kiosk. With this specification we ignore a slight asymmetry that occurs at the last tap to the far right. There is no need for a pipe between the tap and $\tilde{s}$ We still include this branch to keep the model symmetric and, hence, simple. The asymmetry will disapear in a model that is based on a circular city.

[13] See Appendix 1.

[14] The derivation presupposes that the relevant parameters are such that a inner solution exists, i.e. $n>0$, $0<\dot{s}<\bar{s}$. See Appendix 1.

[15] Recall that $n=T/\bar{s}$.

[16] See Appendix 1.

$$\max_{\{\tilde{s},\hat{s}\}}[\int_0^{\tilde{s}} V(s)ds - m\tilde{s} + k\hat{s} + \frac{\kappa}{2}\hat{s}^2 - \left[c_1\frac{\bar{s}}{2} + c_2 + r\right](\tilde{s} - \hat{s})] \tag{3.10}$$

The optimality conditions are

$$V(\tilde{s}) - \left[c_1\frac{\bar{s}}{2} + c_2 + r\right] - m = 0 \tag{3.11}$$

$$-k - \kappa\hat{s} + \left[c_1\frac{\bar{s}}{2} + c_2 + r\right] = 0 \tag{3.12}$$

Figure (3.3) depicts the optimality conditions[17].

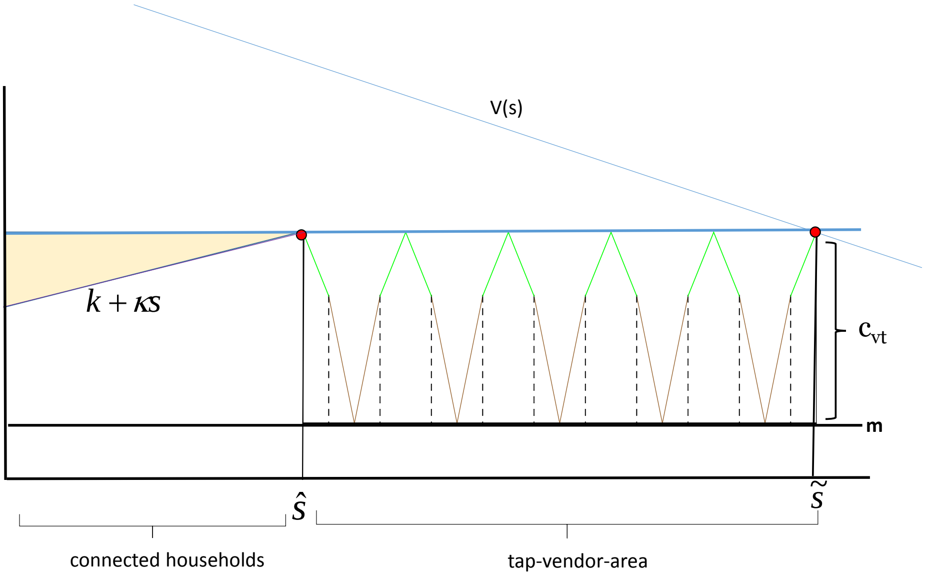

Figure 3.3: Optimal modal split

From left to $\hat{s}$ households are connected to the water utility. At this point marginal costs of water supplied in households are equal to water supply without household connections. To the right of this point the area of water supply by taps and vendors begins. This area ends where total marginal costs $c_{tv} + m$ equals the marginal willingness to pay. This is the optimal modal split of water supply.

The IWRM usually applies a planning approach where economic rents are maximized while taking into account technical constraints, e.g. hydrological laws. However, one must be careful when implementing this concept in practice. Two points are of particular importance.

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[17] Notice once more, that we have simplified the model in that the number of taps are treated as real number. Thus, the model is an approximation of an operation research approach that would apply integer programming methods.

- The pure maximization of the economic rent does not take into account the indispensable human right to water access. The result of Equation (3.10) may lead to $\tilde{s} < \bar{\bar{s}}$. If customers are excluded from the water supply system, we have to correct the optimization procedure by including the constraint $\tilde{s} \geq \bar{\bar{s}}$. Then we end up with a slightly different optimal modal split that covers all customers in the linear city. A brief inspection of Equation (3.12) shows that $\hat{s}$ does not change. Instead, by Equation (3.11), the stretch of the tap-vendor area increases such that at $\bar{\bar{s}}$ the marginal willingness to pay is less than marginal costs.

- The planning approach sets water quantities and the line length of the various service modes in the linear city. In reality, however, consumers and also vendors are not quantity regulated, but only indirectly incentivized through prices. The question must therefore be clarified what prices in the various sections of the route should be fixed. The price determination in turn depends on whether the vendors are employees of the water company or whether they operate independently in a free market. In Section (4), we deal with this issue in more detail.

4 Pricing in unconnected water markets

There is a variety of empirical studies that make price comparisons between connected households and households that depend on the water service of vendor [18]. Most studies conclude that unconnected households are overpriced due to a cartelized supply structure where all players along the vertical production chain try to maximize their rents[19]. The literature describes this overpricing as a “poverty penalty” (See Hailu et al. (2011)).

Rent seeking takes place in various constellations. The lower branch of figure 4.1 depicts the various degrees of cartelization if water utilities follow their rent seeking goal and cannot be effectively regulated due to institutional weaknesses. [20] Regarding to the customer interests, the profit-oriented utility should be regulated in the way that its behavior approach the welfare optimum, minus an “information rent” accruing to it because of imperfect regulation. However, in the absence of regulation, or very imperfect regulation, the water utility may exploit its customers, by setting too high prices, depending on the market structure: in the case of vertical integration, i.e. ownership of both the infrastructure and commercialization, it will exploit customers “efficiently” (case of full monopoly). For instance, Lovei

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[18] See Keener et al. (2009), Kjellén and McGranahan (2006), Kariuki and Schwartz (2005) and Ahmad (2017)

[19] There are some exceptions. See e.g. the vendor system in Ukunda, Kenya, “where a relatively free market exists” (Whittington et al. (1989)).

[20] There also other deficiencies of the water distribution system not included in the figure. Primarily these are leaking pipes and theft of water. (See Chaudhury (2013) and Collignon and Vézina (2000)). In the following, these problems are not addressed.

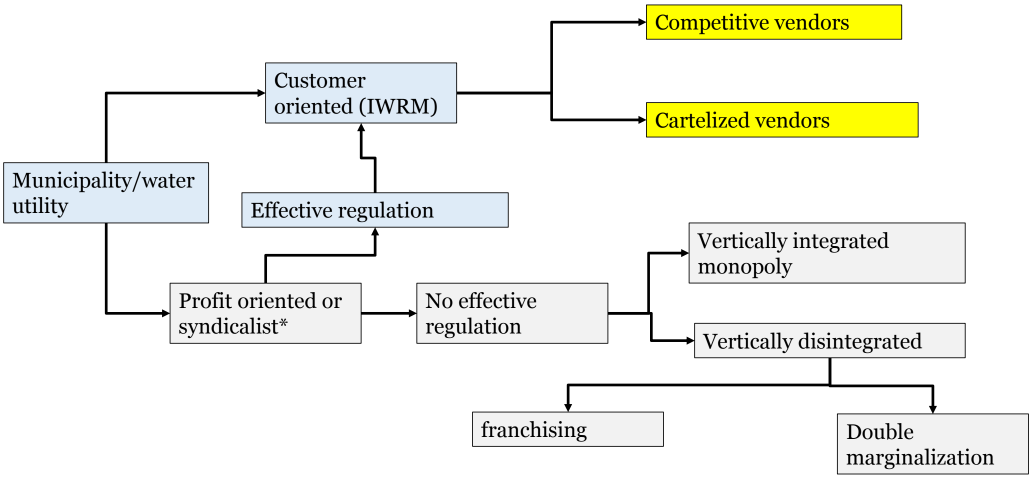

Figure 4.1: market structure

and Whittington (1993) show for the case of a water monopoly, that links the vertical distribution chain of water with franchise contracts, that the tap density is artificially kept scarce to maximize joint profits. Even worse, in the case of vertical disintegration, one expects "double marginalization", i.e. both the utility and the commercial water distributor will exploit their respective market power. [21] As a further sub-case, commercialization can also be carried out by franchise water suppliers.

While the literature empirically examines the existing market conditions or analyzes them in a theoretical framework, we follow a policy approach. In the following sections, a welfare oriented community administration managing a water utility pursuing is introduced. The task of the water utility is to develop a water distribution system that maximizes total welfare of community members and assures the affordable access to water. Thus, we assume the presence of an effective regulating system that allows a policy approach in the spirit if IWRM[22]. However, in a decentralized water market, consisting of collecting customers and vendors, not all prices can be politically regulated. Moreover, regulating prices of connected households and of tap kiosks may have repercussions on the market price at which vendors sell the water. Thus, to provide water to the customers of the linear city the water utility has to follow a cautious regulation policy. In the context of our simple model of a linear city, the water utility has four instruments: the extent of household water connections $\hat{s}$, the density of taps distributed along the line of unconnected house-

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[21] Remember the old result of basic industrial economics: "there is only one thing worse than a monopoly: A chain of monopolies."

[22] See the yellow coloured boxes in Figure 4.1.

holds and the price of water at the tap point $\hat{s}$, whereby the utility can differentiate between customers and vendors. Finally, the water price for connected households can be fixed. The water price in the area where vendors operate cannot directly be regulated. The water utility can try to influence the market outcome by setting a proper water tap price. Thereby, the regulator has to take into account the degree of competition in this market. As mentioned above there are many examples in urban and peri-urban areas that show that the unconnected water market is highly cartelized. These cartels can be very effective in preventing market entry. Often, they operate beyond legal limits[23]. In addition, it is also observable that also both the kiosk manager and the water utility are part of cartels. However, there are also examples where the water market around taps and in the vending area are competitive. In the following we want to analyze both cases.

4.1 Competitive Water Vendors

We start with the assumption that the water market for vendors is fully competitive. They offer water between two consecutive $\dot{s}$-points (See Figure 3.2.). At each location along this segment vendors have the same constant marginal costs with respect to the water quantity offered. In the left scheme of Figure (4.2) the relevant area is magnified. Take two points in close vicinity, s_1 and s_2, where $s_1 < s_2$. Marginal costs with respect to water sold are

$$p_v + c_2 + c_1 s_1 < p_v + c_2 + c_1 s_2 \tag{4.1}$$

where p_v is the price for the vendor at each tap. If a seller A at s_2 wants to sell the water for a price higher than marginal costs, either another seller B occurs at the same point undercutting this prices (Bertrand competition) or B offers the water at point s_1 where the seller A does not operate. But if the price at s_1 is such that $p_1 + \delta(s_2 - s_1) < p_2$ then seller A would loose the demand at s_2 because customers at s_2 will move to s_1 to buy the water from vendor B there. Due to the mobility of customers all selling points are in competition. It does not matter whether we have many or only two vendors in each segment.[24]. The price competition drives all prices down until

$$p(s) = p_v + c_2 + c_1 s \tag{4.2}$$

that is the price is distance dependent and follows exactly along the marginal costs defined in Equation (4.2) where the vending segment is the stretch between two $\dot{s}$-points (see Figure (3.2)). Notice, that the highest price is reached at $p(\bar{s}/2) = p_v + c_2 + c_1\bar{s}/2 = c_{tv}$ where the r.h.s. is defined in Equation (3.9). Customers with

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[23] See Karimi et al. (2010)

[24] As long as the vendors have no capacity limit oligopolistic price competition drives the price to marginal costs (Bertrand-equilibrium). If there are capacity constraints, say vendors cannot shuttle several times between taps and selling location, price competition my not suffice to drive prices down to marginal costs. For oligopolistic price competition with capacity constraints see David M. Kreps and Scheinkman (1983).

the widest distance from the water tap pay the highest price due to the highest marginal costs.

That the water prices correspond to marginal costs follows from the openness of the water market which allows newcomer to invade into the market. Openness is not only due to the absence of legal constraints but also a matter of the very nature of costs. If openness prevails markets are contestable, i.e. entry and exit are costless. This is the case when no costs are sunk for firms leaving the market[25] and no investment into specific capital is necessary for entering the market. If this conditions with respect to the costs structure are fulfilled the number of firms operating in the market is not of importance. Low prices are simply the result of the competition of potential newcomers. If an incumbent charges are price higher than marginal costs (see Equation (4.2)) immediately newcomers invade the market at s driving down the vending price until the equilibrium is reached.

It remains to fix water prices customers and vendors have to pay at each kiosk. After the implementation of the optimal water supply infrastructure, i.e. setting the optimal $\{\bar{s}, \hat{s}, \tilde{s}\}$ according to Equation (3.8), Equation (3.11) and Equation (3.12) the policy maker has also to assure that the division of collecting and vending zones follows the optimal pattern, i.e. locate the modal switching point $\dot{s}$ at the optimal position. This must be achieved indirectly by fixing the water price at each kiosk. In addition, buying water from or selling water to connected households must be inhibited to secure the efficient supply structure. This requires to also fix the water price p_{ch} for connected households.

Unconnected households decide either to buy water from water taps or to purchase it from water vendors. The marginal customer is indifferent between both options, i.e.

$$p_{col} + \delta\dot{s} = p(\dot{s}) = p_v + c_2 + c_1\dot{s} \tag{4.3}$$

where p_{col} (p_v)is the water price charged to the collecting customer (vendor). It is immediately clear from[26] Equation (6.1) that the optimality of $\dot{s}$ requires that $p_{col} = p_v$, i.e. a price discrimination policy would be non-optimal. Finally, we can determine the level of the tap water price. From Equation (3.11) it follows that the marginal willingness to pay must be equal to the marginal costs $c_{vt} = c_1(\bar{s}/2)+c_2+r+m$. The water price vendors charge at $\bar{s}/2$ is $p(\bar{s}/2) = c_1(\bar{s}/2)+c_2+p_v$. Hence, the optimal tap water price is $p_{col} = p_v = r + m$.

To inhibit trade between connected households and adjacent vendors receiving water from the first tap (see Figure (3.3)) we must have at $\hat{s}$:

$$p_{ch} = p(\hat{s}) = c_2 + c_1(\bar{s}/2) + m + r = c_{vt} + m \tag{4.4}$$

Thus, the water price charged to connected households must be equal to marginal cost $c_{tv}+m$ implying that these households pay as much as households in the vending area that are located furthest away from a kiosk.

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[25] The concept of contestability was introduced and elaborated by Baumol (1982).

[26] See also the r.h.s equation in Equation (3.8).

Finally, we have to examine the economic viability of the price system. Total costs of the water utility including transport and distribution costs should be covered by the revenue raised. Cost coverage is aggregated revenues minus costs, i.e.

$$p_{ch}\hat{s} - (k\hat{s} + (\kappa/2)\hat{s}^2) - m\tilde{s} - (\tilde{s} - \hat{s})r - n\rho + p_v(\tilde{s} - \hat{s}) \tag{4.5}$$

which can be rewritten to

$$p_{ch}\hat{s} - (k\hat{s} + (\kappa/2)\hat{s}^2) - m\tilde{s} - n\rho \tag{4.6}$$

since $p_v = m + r$. From Equation (4.4) it follows immediately that cost coverage is

$$[c_{vt}\hat{s} - (k\hat{s} + (\kappa/2)\hat{s}^2)] - n\rho \lesseqgtr 0 \tag{4.7}$$

the sign of which depends on the magnitude of the bracketed term in comparison to total fixed costs of kiosks. The yellow triangle in Figure (3.3) represents the bracketed term. Since all prices are needed as instruments to ensure efficiency and access to water, the policy maker has to look after a further instrument to ensure cost coverage (or to avoid profits). One option could be to introduce an access fee for all connected households. Of course, the precise height does not only depend on the sign of Equation (4.7) but also on income effects which are not modeled in this analytical framework.

4.2 Cartelized Water Vendors

There are many reasons for the fact that the water supply of local water suppliers does not reach the poor in the peri-urban area (see Karimi et al. (2010) and Hailu et al. (2011)):

- Some utilities simply lack the technical and organizational know-how or lack the required entrepreneurial skills and spirit.
- The low income urban areas are seen as no-go areas for utilities. These areas are dominated by local water cartels that prevent a utility from extending its services into their supply area. This cartels can consist of water vendors receiving water from the water mains and selling it to the poors. It is very well known, that water from mobile water vendors is much more expensive than the water for connected households (see Kjellén and McGranahan (2006).
- Water theft from the piping system makes it impossible for the water suppliers to continue to expand the water supply network. (Hailu et al. (2011))

There are two opinions about the role of small-scale private water providers (see Hailu et al. (2011)). Proponents of the mobile and decentralized supply of water see vendors as pioneers and entrepreneurs that supply those who never will have access to a water connection. Skeptics see the vendors as “predators, who charge high prices and supply poor quality water” (Hailu et al., 2011). The UNDP investigation of Hailu et al. (2011) on the unconnected water market of Kenya, for example, revealed as a result that "for two-thirds of households, expenditure on water is above the affordability threshold. And 57 percent of households consume below the water poverty line."

An optimal water distribution system that includes decentralized modes of water supply cannot solely be based on an centralized water management approach. Instead, it is more promising to rely on an indirect regulation approach by setting proper incentives for cartelized vendors to supply the poor at an affordable price.

In general, there are two approaches that allow to reduce the negative economic and social effects of water supply cartels. Which of the two should be adopted depends on the capacity of the authorities to monitor the compliance of water vendors to regulative provisions.

The first approach simply consists of introducing a zonal price cap for water vendors. The price[27] $\bar{p}(s)$ per, say, liter is optimally set, such that

$$\bar{p}(s) = p_v + c_2 + c_1 s \tag{4.8}$$

If the vendor's cartel comply to the regulated price than the optimal modal split is replicated and customers are not exploited. Of course, this type of regulation is only enforceable if the authorities are capable to monitor the price of vendors. How should it be determined that the sellers have charged an excessive price if customers complain? One way could be to issue water coupons that people can buy for $\bar{p}(s)$ at a water authority[28]. They can buy as many as they want. Vendors have to accept these coupons in exchange for water. They can redeem the collected coupons at a public authority for the same price. Of course, this mechanism only works if the cartel is not able to force further receipts from households in addition to the coupons. This would be the case if the cartel could charge an effectively higher price than the coupon price for the water. If the public institutions are not able to prevent the abuse of this system, price regulation is undermined and the customers pay a water price that an unregulated monopolist would demand.

To guarantee access to water for an affordable price, it is probably better that the regulation takes economic incentives into account instead of direct price regulation, which cannot be enforced if the necessary institutional capacity does not exist. The economic incentives must be set such that the desired regulatory effect on water prices is self-enforcing. Low prices for poor customers must be in the interest of cartelized vendors. This is the second approach.

To utilize incentive instruments the economic behavior of a water vending cartel has to be anticipated. The cartel will employ a price policy that maximizes profits of all cartel members. Let us take a look at one location within the vending area. The cartel will try to charge the highest price possible, i.e. to fix a price that extract

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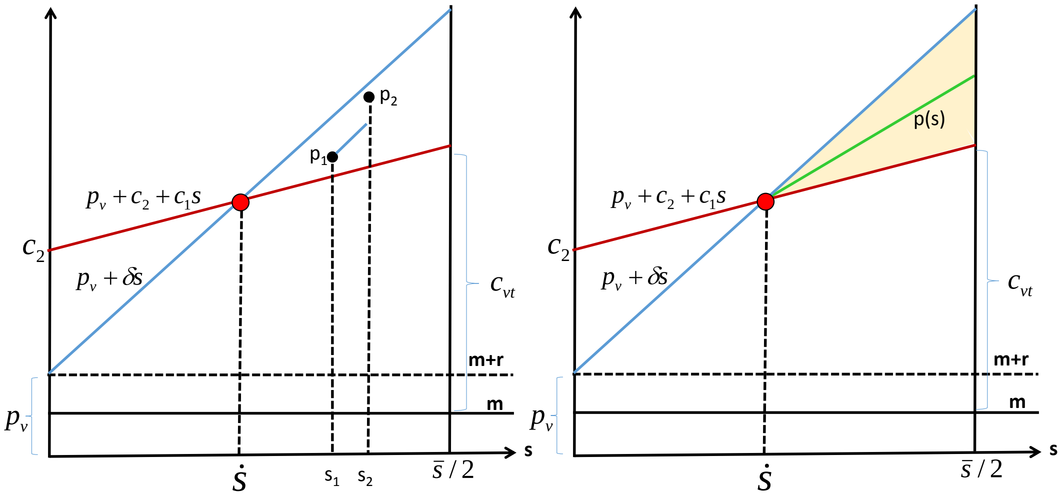
[27] As the linear city model is continuous with respect to the distance s, zonal pricing is expressed by a continuous price function.

[28] The coupon can also be bought from authorized shops located along the stretch of the linear city.



competition

cartelized market

Figure 4.2: competition vs cartel

as much consumer surplus as possible. The upper bound of the cartel price is

$$p_{max}(s) = p_{col} + \delta s \tag{4.9}$$

(see the right hand side in Figure (4.2)). Customers in that location are in this case indifferent between buying water from the cartel or fetching the water from the kiosk. But it could also be that the cartel cannot enforce this price because customers do refuse to buy the water from the vendor. At each point in the vending area we have a bargaining situation. Customers can bargain with the cartel. If, for instance, the cartel tries to charge $p_{max}(s)$ the customer might decline. They can credibly threat the cartel because in the case of decline the cartel would lose profits $p_{max}(s) - p_v - c_2 - c_1 s$. This threat can be utilized by customers at s to stipulate a price below $p_{max}(s)$. One possible analytical way to model the bargaining process is the cooperative Nash solution[29]. For each s in the vending area the cartel is bargaining with the customers a water price. Mathematically:

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[29] The Nash approach belongs to cooperative game theory which assumes that stipulated contracts will be held by its bargaining partners. In addition, the sharing rules are based on axioms and do not model the bargaining process itself.There is a strand of literature from the non-cooperative game theory that models the bargaining process as a sequential game beginning with Rubinstein (1981). More recent contributions also include social preferences into this bargaining process, i.e. include notions of fairness and distributional feelings like envy. See Kohler (2013). To keep the our model simple we restrict our analysis to the Nash concept. From the literature one knows that the non-cooperative solution converges to the Nash solution if discount rates approach zero, i.e. if the bargaining partners are impatient which could be in the case of water an empirically reasonable assumption.

$$\max_p [V(s) - p - \alpha\tau(s) - (V(s) - \delta s - p_{col})] \cdot [p + \tau(s) - c_2 - c_1 s - p_v - 0] \quad (4.10)$$

where $p_{col} = p_v$ are the identical water prices at each kiosk and $0 \leq \alpha \leq 1$. The second bracketed term represents the cartels profits. The threat point is assumed to be zero, i.e. if no contract is concluded the cartel goes without a profit. The function $\tau(s)$ is the zonal coupon price. If the cartel sells water at s it can redeem the coupon for $\tau(s)$. The function will be specified below. The first term in square bracket gives the utility of customers adjusted by the threat point inclosed by round brackets. This threat point is net utility if customers buy water from the kiosk. Customers buy from the utility zonal coupons which costs $\alpha\%$ of the face value τ. If $\alpha = 0$ then customers get the coupons for free, if $\alpha = 1$ customers have to pay the full face value. In the following we assume without loss of generality that $\alpha = 0$, i.e. customers can get coupons for free.[30]

By deriving the first order condition and rearranging terms it is straightforward to find the optimal price function:

$$p(s) = p_v + \frac{c_2 + c_1 s + \delta s - \tau(s)}{2} \quad (4.11)$$

The price function has to be feasible and incentive compatible. Feasibility means that profits are never negative within the vending area and the incentive compatibility property refers to customers. The contract must be such that customers at s have no interest to move either to the right or to the left, so as to buy water for a lower price compared to $p(s)$. Both conditions can be met if $\tau(s)$ exhibits certain properties. We will assume in the following that

$$\tau(s) = t(s - \dot{s}), \quad \forall s \in [\dot{s}, (\bar{s}/2)] \quad \text{and} \quad (c_1 - \delta) \leq t \leq (\delta - c_1) \quad (4.12)$$

where $\dot{s}$ is determined in Equation (3.8).

Moving of customers can be prevented if the slope of the price function is not greater than moving costs, i.e.

$$p'(s) = \frac{c_1 + \delta - \tau'(s)}{2} \leq \delta \quad \Leftrightarrow \quad c_1 + \tau'(s) \leq \delta \quad (4.13)$$

If, for instance, the customer moves to the left, he can buy water for a lower price. But the decrease is less than the marginal fetching costs δ if the condition Equation (4.13) is met. If we take the specification Equation (4.12) into account we see that customers will not move. Feasibility is also met. Inserting Equation (4.11) into the zonal profit function $p(s) + \tau(s) - c_2 - c_1 s - p_v$ yields

$$\pi_{cart}(s) = \delta s + t(s - \dot{s}) - c_2 - c_1 s \geq 0, \quad \forall s \in [\dot{s}, \bar{s}/2] \quad (4.14)$$

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[30] This presupposes that the waterworks can distinguish between customers and suppliers. Otherwise, vendors can get coupons free and redeem them later for the face value. If $\alpha = 1$ this arbitrage opportunity cannot occur. The results of our model also apply to the case $\alpha = 1$.

Hence, zonal profits are an increasing function with $\pi_{cart}(\dot{s}) = 0$. Total profits of vendors between two taps are

$$\Pi_{cart} = 2\int_{\dot{s}}^{\bar{s}/2} \pi_{cart}(s)ds \tag{4.15}$$

Having derived the price function in the vending area we now have to turn to the to issue of incentive regulation. It is rather clear that the price function can be influenced by the zonal coupon price. $\tau(s)$ is able to determine the distribution between consumer surplus and profits of the cartel. Utilizing Equation (4.11) and Equation (4.12) we have:

$$p(s) = \begin{cases} p_v + c_2 + c_1 s & \text{if } t = (\delta - c_1) \\ c_2 + c_1 s \leq p(s) \leq \delta s + p_v & \text{if } c_1 - \delta \leq t \leq (\delta - c_1) \\ \delta s + p_v & \text{if } t = c_1 - \delta \end{cases} \tag{4.16}$$

One price function for the intermediate case is drawn in the right figure of Figure (4.2). It is interesting to observe that the choice of the coupon price determines the exploitation degree of customers. If for example, $t = (\delta - c_1)$ then the price function follows the competitive case and customers are not exploited. However, zonal profits of the cartel are as high as in the case of an unregulated cartel. To see this, one simply has to insert the price function for this case into Equation (4.14) which yields

$$\pi_{cart}(s) = \delta s - c_2 - c_1 s > 0 \tag{4.17}$$

Although the customers pay only the competitive price, the cartel achieves a monopoly profit in each zone. The gap is filled by the effective subsidy the public utility pays to the cartel by redeeming the coupons.[31] So the indirect incentive approach has its price. Since the regulation authority cannot directly enforce marginal cost pricing the cartel is able to extract the monopoly rent. The essential difference between a unregulated market and the subsidized market[32] is, that the public authority is financing the monopoly rent instead of the customers.

5 Conclusion

Water vendors play an important role in the delivering of water especially for those households which do not have access to the municipal water supply. Ambitious political goals such as the human right to water and the Sustainable Development

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[31] Our coupon system has a resemblance to the prominent Loeb Magat-Mechanism. This mechanism regulates a Cournot-monopoly by subsidizing it. The subsidy is simply the consumer surplus which results from the price setting of monopoly. If the monopoly takes this subsidy into account it is in the very interest of her to set the price equal to marginal costs. This leads to efficiency and the protection of consumers. However, the monopoly reaps full profits which are financed by subsidies. (Loeb and Magat, 1979)

[32] Note, that the subsidy can also be negative, i.e. the policy maker can raise a tax. In this case customers will be more exploited. See Equation (4.16).

Goal No. 6 postulates the claim that every human being should have access to an adequate and affordable water supply. From an economic standpoint of view, water vendors should play a central role to meet this goal, because we found a modal split for the optimal provision of water. This means that only a portion of households should be served by the public utility. The residual households which are not connected to the water supply network should be served by either mobile water vendors or water kiosks. Therefore, the location of the respective consumer affects its optimal mode of supply. The modal split could be found with the help of a micro-economic model. For simplification reasons, some assumption was made, for instance the linear city, totally inelastic demand functions, a simple cost structure for the public utility, the vendors and the water consumers.

A multitude of forms of the water vendors market structure is conceivable. In this analysis, we focus on vendors that compete against each other on the one hand, and form a cartel on the other hand. For the case of competitive water vendors, the informal water market is contestable and the water utility fix the water prices at the kiosks for the collectors and the mobile vendors. Therefore, an equilibrium can be found which replicates the optimal modal split solution. However, if water vendors form a cartel, intervention in the market is needed to prevent the abuse of market power by the vendors. Therefore two alternative price regulation approaches are addressed: Firstly, the cost related zonal price cap, and secondly a subsidizing strategy of the cartel to incentivize the vendors cartel to reduce the prices.

Of course, there exist some limitations, which are not addressed in this modeling approach. For instance, usually the water demand is price responsive, which requires a demand function which is not totally inelastic. Also the effect of income is not addressed in the presented modeling approach. Furthermore, the modeled city is greatly simplified compared to real, existing cities due to the assumed homogenous spatial structure of costs and demand. Opportunistic behavior (e.g. water-theft due to hidden information) as well as different forms of collusion between the actors in the informal water market, which occur quite often in reality, are not implemented and analyzed in this framework. Hence, further research is needed to extend the model and include additional features.

6 Appendix

6.1 Appendix 1

The Karush-Kuhn-Tucker conditions to the minimization program equation (3.7) are:

$$2n\delta\dot{s} - 2nc_1\dot{s} - 2nc_2 - \mu \geq 0 \tag{6.1}$$

$$n(c_1/2)\bar{s} + nc_2 + rn - \lambda n + (\mu/2) = 0 \tag{6.2}$$

$$2\left[\frac{\delta}{2}\dot{s}^2 + \frac{c_1}{2}[(\frac{\bar{s}}{2})^2 - \dot{s}^2] + c_2[(\frac{\bar{s}}{s}) - \dot{s}]\right] + r\bar{s} + \rho - \lambda\bar{s} = 0 \tag{6.3}$$

where the Lagrangean λ ($\mu \leq 0$) refers to the first (second) constraint.

Two cases can be distinguished: either it is not optimal to have vendors at all or there exists an optimal mix of collecting and vending. The occurrence of the two cases depends on certain parameter constellations. Let us begin by assuming that $\dot{s} < (\bar{s})/2$, i.e. a mixed supply area is optimal. We know from the KKT-conditions that in this case $\mu = 0$. The optimal collecting area $\dot{s}$ follows from Equation (6.1) immediately. To derive the optimal distance between two taps $\bar{s}$ solve Equation (6.2) for λ, multiply it by $\bar{s}$ and insert it for $\bar{s}\lambda$ in Equation (6.3). The equation reduces then to

$$-c_2\dot{s} - \frac{c_1}{4}\bar{s}^2 + \rho = 0 \tag{6.4}$$

which can be solved for $\bar{s}$ yielding Equation (3.8).

We have assumed that $\dot{s} < (\bar{s})/2$. Inserting the solutions from Equation (3.8) leads to

$$\frac{c_2}{\delta - c_1} = \sqrt{\frac{\rho(\delta - c_1) - c_2^2}{(\delta - c_1)c_1}} \tag{6.5}$$

Rearranging and reducing yields the parameter constellation

$$c_2 < \sqrt{(\rho/\delta)}(\delta - c_1) \tag{6.6}$$

as a necessary and sufficient condition for $\dot{s} < (\bar{s})/2$.

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