Digital TV

SUMMARY

This paper studies the role of economic policy for the transition from analogue to digital television, with particular attention to the switch off of the analogue terrestrial signal. The analogue signal cannot be credibly switched off until almost all viewers have migrated to digital, due to the policy objective of universal access to television. But before switch off, only part of the population can be reached with the digital signal. In addition, those who are reached need to spend more to upgrade their reception equipment than after switch off, because the capacity to increase the power of the digital signal will be made available only then.

After reviewing the competitive structure and the role of government intervention in television markets, we present the early experience of a number of industrialized countries in the transition to digital television. We then formulate a micro-econometric model of digital television adoption by individual viewers. The model is calibrated to UK data and simulated to predict the impact of government policies on the take-up of digital television. Policy makers can affect the speed of take up of digital television by: (1) controlling the quality of the signals and the content of public service broadcasters; (2) intervening in the market for digital equipment with subsidies; and (3) publicizing the conditions and date of switch off of the analogue signal. We find that if the analogue terrestrial signal is switched off only when certain aggregate adoption targets are reached, strategic delays may arise and expectations may affect the success of the switch off policy.

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The transition to digital television*

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1. INTRODUCTION

The wonders of digital television have been heralded for more than two decades.[1] Compared to the old analogue technology, digital compression allows more channels to be transmitted with better image quality and improved interactive applications. Roughly six times as many channels can be broadcast with the same amount of transmission capacity as is currently used for one analogue channel. The switch off of the analogue signal could result in a large increase in the supply of television channels available to viewers or in bandwidth being freed up for other uses.

This paper aims at providing a framework for discussing the policies for the transition from analogue to digital television. The transition requires that broadcasters

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[1] The US Federal Communications Commission began its first inquiry into what was then called 'advanced television' in 1987.

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invest in new transmission plants and that viewers buy reception equipment to decode the digital signal. The incentives for viewers to switch to digital depend on the cost of this equipment and the availability of digital services with valuable content. In turn, content providers have few incentives to make good content available digitally until digital broadcasting attracts a large number of viewers. In addition, digital equipment also tends to be expensive if its demand is low. Due to this 'chicken and egg' feature, digital conversion of each network requires a fair amount of *co-ordination* among the different stakeholders.

The need for co-ordination is exacerbated by the *public good* nature of the *delivery* technology used for broadcasting.[2] Broadcast delivery is non-rival, because the reception of the signal by any viewer does not reduce the availability of the same signal to other viewers.[3] This allows a large amount of identical content (packaged in channels) to be transmitted to all the connected viewers.[4] But then a significant amount of bandwidth must be used to reach the remaining analogue viewers (even if they are not numerous), making it impossible to deploy that bandwidth for digital transmission or other uses.

1.1. Business policy

This problem arises to a different extent for the three main television delivery media: terrestrial,[5] cable and satellite. The costs and benefits of transition from analogue to digital vary across platforms, depending mostly on the cost and scarcity of transmission capacity. But if digitization is economical for a platform, there is a strong case for a rapid transition so that duplication of the transmission costs necessary to reach old (analogue) as well as new (digital) viewers can be avoided.

To take full advantage of digital broadcasting, co-ordination is necessary among owners of the delivery medium, providers of broadcast content, equipment manufacturers and viewers. Since costs and benefits are unevenly distributed among these players, it is natural to expect that the owners of the delivery platform would co-ordinate the migration. Indeed, pay television satellite operators have completed a

[2] A few definitions are in order. A good is said to be *non-rival* if one person's consumption of the good does not reduce the ability of other consumers to consume it. A good is *non-excludable* if people cannot be excluded from consuming it. A *pure public good* is non-rival and non-excludable. Before the advent of encryption technology, over the air broadcasting was the perfect example of a pure public good. An *excludable public good* is non-rival. Since the cost of provision of an excludable public good is constant, the average cost decreases with the number of units sold. An excludable public good is equivalent to a *natural monopoly*.

[3] Equivalently, the cost of delivery of any given signal does not depend on the number of (connected) viewers who actually tune in. Delivery through broadcasting is effective for the purpose of transmitting a large amount of information to many receivers. One-to-one communication (or 'narrowcasting') requires instead more bandwidth and so can allow the transmission of less content. Nevertheless, in the near future it will be possible to transmit video on demand through broadband and especially optical fibre cable to the home.

[4] At each point in time, each viewer then selects the channel to which to tune in.

[5] 'Terrestrial' refers to broadcasting by a land-based radio transmitter.

swift migration from analogue to digital for all their viewers in a number of European countries. During the transition stage, operators have employed more bandwidth in the form of costly satellite transponder space. In order to speed up the switch by their subscribers, they have replaced millions of old analogue decoders with new digital decoders at no additional cost to their viewers. Essentially, the platform operators have 'internalized' the externalities among the different players.

1.2. Public policy

The transition to digital television might be an interesting business strategy case, but is it a public policy issue? We argue that governments have important stakes in the transition to digital *terrestrial* television, due to the interplay of two factors.

First, governments own the radio spectrum employed for terrestrial broadcasting. This spectrum is currently used for free-to-air (FTA) television in virtually every country, and in Europe it is partly allocated to public service broadcasters (PSB), often run by government-owned corporations.

Second, access by the entire population to the information diffused through television by the traditional FTA and the PSB channels is widely believed to be a democratic right. In addition, choice, plurality and competition in television markets are typically considered to be important not only for economic but also for social and political reasons.

There is an inherent conflict between the *economic* role of the government as owner of the terrestrial spectrum, and its *social* objective of universal access and plurality. Viewers can enjoy the full benefits of digital terrestrial television in terms of coverage and portability only after the analogue signal has been switched off and the power of the digital signal increased. But governments have their hands tied, because it is politically difficult to switch off the analogue signal until almost all households have converted their equipment to digital. Hence viewers have limited incentives to migrate to digital during the transition stage.

The Commission of the European Communities (2003a) has stressed that it does not intend to impose uniform policies across Europe, but rather to ensure that policy makers in different countries are well prepared for the switchover.[6] Given the many options available and their differential impact on the stakeholders, economic analysis has a lot to contribute to the process of policy formation.

[6] See also the action plan of the European Commission on information society entitled 'eEurope 2005' (2002): 'In order to speed up the transition to digital television, Member States should create transparency as far as the conditions for the envisaged switchover are concerned. Member States should publish by end 2003 their intentions regarding a possible switchover. These could include a road map, and an assessment of market conditions, and possibly a date for the closure of analogue terrestrial television broadcasting which would enable the recovery and refarming of frequencies. National switchover plans should also be an opportunity to demonstrate a platform-neutral approach to digital television, taking into account competing delivery mechanisms (primarily satellite, cable and terrestrial).'

1.3. Our approach

We begin by reviewing the competitive and regulatory structure of television markets. Current conditions in television markets differ across countries due to different historical developments, driven mostly by political and geographical considerations. We also discuss the early experience of some industrialized countries in the transition process.

We then develop a micro-econometric model designed to analyse the impact of policies aimed at affecting digital take up by viewers. In our model, in each period individual viewers optimally choose which delivery platform and package of channels to adopt for their primary television set. The adoption decision is inherently dynamic, because it is based on a comparison of the one-off current cost of reception equipment with the flow of associated future benefits. Current and future prices and the characteristics of platforms in terms of content and coverage are given parameters, assumed to be known by the viewers. Viewers expect the switch off date to happen at a given future date. The cost of terrestrial set-top boxes depends on its cumulative adoption, and is determined as part of the solution of the model.

For illustrative purposes, we calibrate the model to the UK market by combining three main sources for data. First, we recover the consumer preferences from estimations based on a recent survey of UK viewers with hypothetical choice questions. Second, we estimate a simple model of the evolution of prices of terrestrial decoders depending on cumulative production. Third, we set the initial conditions of the model based on publicly available data of historical adoption of different platforms.

We use the model to simulate the impact on take up of a number of policies that have been employed in some countries or are currently under consideration. The output of the model is used to compute the effect of these policies on consumer surplus.

The paper proceeds as follows. Section 2 gives a brief overview of competition and regulation in television markets. Section 3 reviews the current status of digital switch-over in some countries. Section 4 introduces our modelling methodology. Section 5 reports the results of a number of policy experiments. Section 6 concludes.

2. TELEVISION IN TRANSITION: COMPETITION AND REGULATION

In this section we discuss the main features of television markets in industrialized countries and the ways in which governments intervene in these markets, with particular reference to the transition to digital television.

2.1. Television markets

In most industrialized countries viewers can opt for *free-to-air* (FTA) *television* or *pay television*. Almost every citizen can receive a limited number of FTA channels, through a rooftop aerial that receives the analogue terrestrial signal. There are typically two classes of free-to-air channels: public and commercial channels. *Public channels* are typically financed by the television licence fee (in Europe), contributions by viewers (in the US) and often also through advertising. *Commercial channels* are instead financed mostly with advertising revenues. As explained below, access and content of FTA channels is subject to government regulation.

Over the last three decades, viewers' choice has drastically improved in many countries with the introduction of pay television platforms, which broadcast mostly through cable and/or satellite. Typically, pay television operators offer FTA as well as a large number of other channels, charging monthly subscription fees according to the package of channels selected by the viewers.

Due to digitization of the broadcasting technology, this distinction between FTA and pay television is fading. For example, UK viewers interested in seeing more than the five FTA analogue channels often have two options. They can either sign a contract with the satellite or cable operator with a periodic subscription fee but no upfront charge for the provision of the necessary reception equipment (digital decoder, also known as 'set-top box', and satellite antenna if necessary). Alternatively, they can purchase a digital terrestrial decoder, enabling the reception of more than twenty free terrestrial channels without paying a subscription fee. The choice is essentially between services with different content and different payment schedules over time. Effectively, free-to-air and pay television compete in the same market for viewers, programme content and advertisers.[7]

Given our focus on the retail market, we discuss content *production* only briefly. The key feature of this production is that it involves a high fixed cost, but negligible marginal cost with respect to the number of viewers. This is because the electronic technology allows virtually costless replication of the content, or, put otherwise, the consumption by viewers is non-rival (see footnote 2).[8] As a result, content is often made available on different platforms in the upstream market, as discussed below.

We now turn to a discussion of the different stages of competition in television markets, the advantages and disadvantages of the different platforms available for broadcasting, and the digitization process.

2.1.1. Stages of competition. Before the arrival of satellite, access to pay television could mostly be provided only through cable. Due to the natural monopoly nature of cable networks, it is rare that more than one cable operator serves the same domestic residence. As a result, local cable operator had monopoly power vis-à-vis

[7] See Armstrong (2002) and Rochet and Tirole (2003) on the analysis of competition in two-sided markets.

[8] Note that the public good nature of content production is different from the public good nature of broadcast delivery discussed in the introduction. To appreciate the difference, notice that a film is rival in consumption if distributed through DVD, but non-rival if distributed through a broadcast network. But in both cases, the marginal cost of serving an additional viewer is very small.

both viewers and programme providers. This raised the issue of allowing programme providers access to the cable network, to prevent vertically integrated cable operators from foreclosing rivals in the market for programme content.[9]

With the advent of satellite and now digital terrestrial television, many households can now choose the platform with the most attractive multi-channel offer. Competition between broadcasting operators controlling different platforms takes place in three phases:

- *Upstream market*: In the upstream market different broadcasting operators compete to obtain proprietary content, and in particular premium content. Operators compete for the exclusive (and often resaleable) rights to premium programme content, such as broadcasting rights to sport events and recently released films. The outcome of competition in the upstream market affects the position of all operators in the wholesale and retail markets.
- *Wholesale market*: In the wholesale market the operator that won the upstream competition negotiates the terms of access to this content with the other operators. Operators without premium content are particularly interested in gaining access to it. The 'selling' operator typically charges a variable fee to the 'buying' operators for each of their viewers subscribing to the premium package. Buying operators can then offer premium content to their viewers, but have to pay the per-subscriber fee to the selling operator.
- *Retail market*: In the retail market, operators compete to attract viewers to their platform, by designing the characteristics and prices of their packages of programmes. The products offered by the broadcasters are typically differentiated both in the means of delivery and in the content of the programming packages offered. Operators frequently offer subsidized reception equipment in order to attract viewers to their platform.

Pay television operators typically offer packages of 'basic' programmes that must be taken by all subscribers. Basic packages vary across operators and usually include terrestrial (PSB and commercial) channels, as well as other channels, interactive services and radio stations. By paying a supplementary fee, subscribers can also purchase 'premium' programmes, such as major sports events and Hollywood movies.[10] Access to premium programming is widely viewed as being crucial for attracting viewers to a platform.

Note that with the increase of downstream competition, the bottleneck is now shifting upstream. While the old focus of competition policy was the access of programmes to the dominant network (controlling competing programmes), the new

[9] See Waterman and Weiss (1997) and Crawford (2000) for analyses of the US experience in the regulation of vertically integrated cable companies. See Armstrong (1999) and Harbord and Ottaviani (2001) for overviews of content provision in the UK pay television market. See Crawford (2000) and Goolsbee and Petrin (2004) on competition across platforms in the US.

[10] For example, in the UK in 2001 BSkyB offered a choice between three basic packages with increasing number of channels (value, popular and family) and offers two premium film channels (Moviemax and Sky Premiere) and two premium sport channels (Sky Sports 1 and 2).

focus is the access of networks to the dominant premium programme (controlled by a competing network).

Given our interest in the viewers' platform adoption decision, this paper focuses on the retail market. Though our model treats television subscription prices as given, it is important to realize that the outcomes of retail competition heavily depend on the availability and cost of content for the competing operators, and so are affected by the first two stages of competition.

2.1.2. Delivery platforms. In the retail market there are a number of platforms that deliver television content to viewers by employing different broadcasting technologies. Currently, there are three main technologies:

- *Terrestrial*: This is the oldest and most commonly used technology for television broadcasting. Traditionally, television is broadcast terrestrially with analogue signals using the ultrahigh frequency (UHF) band. For technical reasons, the part of the electromagnetic spectrum that is particularly apt for ground-to-ground transmission is severely limited. As a result, only a very limited number of channels can be broadcast analogically. Even though analogue channels can be scrambled, analogue channels are typically available for free to everyone who tunes in.
- *Cable*: In order to be able to receive cable television, a direct cable connection from an underground cable network to the home is needed. Cable technology enables many more channels to be broadcast than terrestrial technology. Though cable television was first introduced in areas of rural America with poor terrestrial signals, cable networks now tend to be predominant in densely populated, urban areas where building the network is more economical.
- *Satellite*: Like cable, home satellite systems first developed with rural TV viewers who had limited access to other platforms and could purchase large and expensive parabolic antennas. With improvements in satellite technology, from the late 1980s commercial satellite operators began to compete with cable. In order to receive the satellite signal, there must be a clear line of sight from the receiver (also called 'dish') to the broadcast satellite. Some viewers cannot access satellite signals due to terrain screening (such as mountains or cliffs), local obstructions (such as trees or neighbouring buildings) or planning restrictions.

It is now also technically possible to transmit television using broadband Digital Subscriber Line (DSL) technology, which allows high bandwidth data transmission on a conventional residential telephone line. Although the current penetration of this platform is negligible, this platform is expected to grow in the future. In this study, we will disregard this platform owing to lack of market information.

The average cost of reaching viewers with different delivery mechanisms depends on the population density. A highly concentrated population is cheaply served by cable, while satellite is ideal to reach areas with low population density. Each delivery platform has strengths and weaknesses:

Table 1. Penetration of television platforms in the EU (2003)

Country	Terrestrial (%)	Cable (%)	Satellite (%)
Austria	9.6	40.8	49.6
Belgium	5.0	93.0	2.0
Denmark	27.1	46.4	26.5
Finland	45.6	43.9	10.5
France	67.6	11.9	20.5
Germany	5.4	56.3	38.3
Greece	91.4	0.0	8.6
Ireland	35.5	35.8	28.7
Italy	84.2	0.3	15.5
Luxembourg	2.4	91.7	5.8
Netherlands	7.2	89.0	3.8
Portugal	58.1	28.7	13.2
Spain	78.5	7.1	14.3
Sweden	35.0	47.1	17.9
UK	53.2	15.6	31.3
Total EU	45.5	30.3	24.2

Notes: For each country, this table breaks down the television households by delivery platform used for the primary television set.

Source: Commission of the European Communities (2003b, p. 99).

- The main advantage of terrestrial is higher portability, that is, the possibility of receiving the signal even with a small aerial, provided that transmission power is sufficiently strong.[11] Its main disadvantage is the severe limitation in bandwidth and limited interactivity.
- The advantages of cable are its high bandwidth capacity (even with analogue technology) and its high potential for interactivity (a return path built into the cable enables two-way communication). Its disadvantages are a high upfront cost of building the network and limited portability.
- The main advantage of satellite is its relatively low upfront cost of network construction, as this can be done by renting satellite transponder space. Its disadvantages are limited interactivity and portability.

As illustrated in Table 1, EU countries differ widely in terms of the adoption of television platforms. For the purpose of the transition to digital, it is useful to classify countries according to whether they have a strong terrestrial presence, as done in the BIPE (2002) report:

- *Terrestrial countries*, with a large fraction of households viewing FTA terrestrial television. In most southern and western European countries (France, Greece, Italy, Spain, Portugal) the large majority of households receive television exclusively through the terrestrial signal. Terrestrial penetration is also strong in the UK.

[11] Portability is believed to be the main advantage of the DVB-T standard adopted in Europe for terrestrial broadcasting over the American ATSC standard.

- *Non-terrestrial countries*, typically with good penetration of cable. These are mostly central and northern European countries, such as the Benelux, Germany, Austria, Denmark, Finland, and Sweden. Eastern European countries are in a similar situation. In these countries, a sizeable range of channels is already available to viewers via basic access.

In our opinion, these differences are due to a combination of political, geographic and market factors. As in the case of the roll out of terrestrial television, central and local governments have played a major role in building cable networks. For example, in Germany the cable system was initially owned by the state telecommunications monopoly, Deutsche Telecom. The government also supported the spread of cable television via legislation permitting private companies to serve the last mile to the customer.

More densely populated countries seem to have higher penetration of cable. This is probably because the cost of constructing the cable network is lower in a densely populated country. Small countries that share borders with many neighbours are subject to greater international interferences and so have less terrestrial spectrum available for broadcasting, resulting in higher benefits of cable over terrestrial.

The high penetration of cable in some countries could be due to an initial head start of a few years. Market conditions changed with the arrival of direct-to-home satellite television in the early 1990s. The cost of connecting an additional viewer for a satellite network is relatively low, while laying new cable is more costly and time consuming. Due also to the natural monopoly nature of broadcasting, cable lost some of its commercial appeal. These circumstances could explain the differences in the penetration of delivery platforms across Europe.

2.1.3. Digitization. Broadcasting can be either analogue or digital on each of the three delivery platforms, but the costs and benefits of digitization vary:

- *Digital terrestrial television (DTT)*: Digital compression technology allows roughly six times as many channels to be broadcast with the same amount of spectrum used by one analogue channel. DTT signals are received through conventional TV aerials and can be converted into analogue form by a set-top box (STB) or viewed with an integrated digital television set (IDTV). Digital terrestrial television gives viewers access to an increased supply of basic channels.
- *Digital cable*: Digitization of existing cable networks requires investments by the cable operator. It is onerous to convert existing cable networks to digital, due to the necessary re-wiring. In addition, a digital STB is required for digital reception, different from the one needed for DTT. The benefits in terms of improved interactivity are major, but the increase in channel capacity is not very valuable because existing analogue cable networks already have very high channel capacity.
- *Digital satellite*: Digital satellite is also referred to as direct to home (DTH). In addition to the satellite aerial, a specific digital STB is required for digital reception.

Table 2. Digitization by platform in the EU (2003)

Country	Terrestrial (%)	Cable (%)	Satellite (%)
Austria	0	4	31
Belgium	0	4	25
Denmark	0	8	45
Finland	7	2	42
France	0	32	74
Germany	19	8	22
Greece	0	0	98
Ireland	0	21	95
Italy	0	0	88
Luxembourg	0	1	72
Netherlands	6	2	100
Portugal	0	2	100
Spain	2	17	100
Sweden	13	8	100
UK	22	60	100

Notes: For each country and delivery platform, this table gives the percentage of television households with digital reception. The remaining fraction is served by the corresponding analogue service.

Source: Our elaboration based on information published in Commission of the European Communities (2003b, pp. 99 and 104).

> There are great benefits in terms of reduced transponder costs and, equivalently, increased channel capacity for given transponder space.

These three multi-channel delivery systems cover different but partially overlapping segments of the population. For example, in the UK DTT currently covers 80% of the population, cable is available to roughly 50% of the population (mainly in urban areas), and satellite is believed to cover most (96–98%) of the population (see Independent Television Commission and the British Broadcasting Corporation, 2003). As discussed below, additional DTT power to cover 95% of the population will be available only after the analogue signal has been at least partly switched off.

Table 2 shows the percentage of television households with digital reception, broken down by platform and European country. While satellite networks are largely digital, cable networks are still mostly analogue, and terrestrial are almost entirely analogue. We believe that take up of digital satellite is largely due to the favourable cost/benefit analysis, while the slow adoption of digital cable is due to lower benefits associated to digitization, as well as to the more difficult financial position of cable operators. The different outcomes for terrestrial television are due to different public policies.

We believe that digitization of satellite and cable does not raise direct public policy concerns, because these platforms do not use scarce UHF spectrum. Satellite and cable networks are managed by private companies. It is natural to expect that the owners of these networks will decide to digitalize broadcasting on their platform, provided that it is profitable.

As we explain in more detail below, the main public policy problem arises for the digitization of the analogue terrestrial network. When analysing our model we will therefore report the fraction of television households that do not adopt one of the three multi-channel television platforms (DTT, cable or satellite) and choose to view television exclusively through the terrestrial analogue platform.[12]

2.2. Television and the government

Governments play a key role in allocating resources, controlling content and regulating competition in the television industry. Beyond the consumer welfare and corporate profit at stake in broadcasting markets, important non-economic repercussions, such as political democracy and social cohesion come into play. When intervening in television markets, governments have a tangled web of economic, political and social goals. As often happens when such a mix of interests is involved, the policy debate is easily tainted by partisan claims.

In this section we attempt to disentangle these different goals, with the aim of evaluating the merits and drawbacks of government intervention. We then address the public policy issues related to digital transition.

2.2.1. Governance of television. In almost any country, governments effectively decide which technologies can be used for broadcasting, which broadcasters should be allowed to use these technologies and what kind of content can be shown to viewers.

2.2.1.1. Economic motives. A first rationale for government intervention is economic and is based on the technological characteristics of broadcasting. Three components are necessary for television production and consumption: (1) programming has to be produced; (2) it has to be broadcast; and, (3) viewers must have television sets to receive it. Producers, broadcasters and viewers are required to make concerted investments for the success of television. Because the return of the investment of each of these three players increases with the other players' level of investment, there is some need for co-ordination to kick-start the process.

Indeed, governments have been heavily involved in co-ordinating the development of television, since its inception 50 years ago.[13] In accordance with the lessons learnt in the management of radio broadcasting, exclusive licences for television broadcasters were deemed necessary in order to avoid interferences. National governments across

[12] Although most households tend to have more than one television set on average, in our model we focus on the reception equipment necessary for the main television set. Many households currently view FTA analogue television from the secondary television, even though they have access to multichannel television services through their main set. Our model can be extended to consider the incentives for conversion of secondary television sets.

[13] See Chapter 12 of Rohlfs (2001) for a discussion of the involvement of the US government in co-ordinating television standardization processes. See Faulhaber and Farber (2004) for an account of how licences for television broadcasting came about in the US.

the globe assumed responsibility for the allocation and assignment of electromagnetic spectrum within their borders and co-ordinated with neighbouring countries in order to avoid cross-border interferences. Administrative procedures were put in place to determine the part of the spectrum allocated to television. This spectrum was then assigned to broadcasters, typically by means of bureaucratic procedures. In addition, governments actively co-operated with industry to set and often mandate common standards.

The allocation of spectrum for television broadcasting is determined by international agreements, intended to avoid interferences across countries. For example, in the UK the spectrum allocated to terrestrial television is located between 470 MHz and 862 MHz in the radio spectrum in the Ultra High Frequency (UHF) band. The portion of this spectrum that can be used for broadcasting is split into 46 channel frequencies of 8 MHz each, the remaining portion being allocated to radar, VCRs and radio astronomy. In total, 368 MHz can be used for terrestrial broadcasting, in the analogue and/or the digital mode, as well as for other non-broadcast communication purposes such as wireless phones and personal communication devices.

Since Coase (1959), many economists have argued that the market might be in a better position than the government to determine the allocation of the radio spectrum. According to this view, privatization would result in the spectrum being used more efficiently and in co-ordination problems coming to an end. The initial allocation of property rights could be determined by means of auction mechanisms. Re-trading of the rights would also be allowed and no administrative restrictions would be imposed on how the spectrum is used (cf. Rosston and Hazlett, 2001). While we believe that privatization and trading of the spectrum should be also seriously considered for the UHF segment of the spectrum, these solutions have not yet been adopted. In addition, governments have generally not yet announced what use will be made of the freed spectrum after switch off.[14]

Finally, competition policy concerns apply to the television market. Due to the presence of large fixed costs in production and network effects in distribution, this market is naturally prone to anti-competitive behaviour (cf. Motta and Polo, 1997). Competition should then be promoted in these markets, as in any other market, in order to promote economic efficiency. Special legislation has been drafted in many countries with a view to safeguarding competition in media markets. These measures are often motivated by the non-economic factors discussed below.

2.2.1.2. Socio-political motives. Government intervention in broadcasting has gone well beyond the allocation of the radio spectrum. In almost all countries, with the notable exception of the US, governments have become directly involved in the production and distribution of television content via public service broadcasters. PSB television was the natural continuation and development of public radio and started in the 1920s

[14] See the discussion in Cramton *et al.* (1998) on the possibility of designing mechanisms to allocate the spectrum while it is still occupied by analogue broadcasters.

and 1930s in most European countries. While government-controlled broadcasting has been eschewed in the US, in most European countries public service broadcasting was still the dominant mode of programme origination and distribution until the mid 1980s. Financed either exclusively by licence fees (e.g., the UK) or a combination of licence fees and advertising (e.g., Italy), public service broadcasters in Europe have been under direct state control through regulation of both transmission and content.

The arguments traditionally put forward in favour of PSB are mostly non-economic in nature. There are two main socio-political reasons for government intervention. First, governments have often used broadcasting as a tool for achieving cultural objectives, often with the aim of strengthening national cultural identity. Television broadcasting is considered a 'merit good', akin to education (cf. Graham and Davies, 1997). In addition, governments have actively regulated content in order to preserve moral decency and quality of programmes.

Second, free television is considered important for the democratic process. Freedom of speech and pluralism of information are considered fundamental rights upon which modern democracies are based. In order to preserve these rights, many Western countries have imposed stricter criteria for ownership concentration in media than in regular markets. This legislation should prevent single corporations or individuals from unduly influencing public opinion.

Governments have used these objectives of quality and pluralism to justify their direct involvement in television production and the regulation of the content shown by private broadcasters. For the purpose of our analysis, the main implication of these non-economic goals is the policy of *universality*. Many governments see universal access to television as essential to the full social, political and economic inclusion of its citizens.[15] In practice, the universality objective has typically been attained by direct public control of terrestrial broadcasting. It is worth noting that government objectives such as universality could be achieved through regulatory interventions, without the government retaining ownership of the spectrum and being directly involved in broadcasting, as also argued by Elstein *et al.* (2004).

Quality, pluralism and universality are thorny issues. The risk is that governments' real motives for intervening in media are different. As argued by the public choice tradition, and recently empirically confirmed in a cross-country study by Djankov *et al.* (2003), policy interventions might unduly take place in media markets to foster the particular interests of political elites or entrenched governments. Regardless of their

[15] For an extensive discussion of universal access in broadcasting see the UK Government's Communications White Paper 'A New Future for Communications', Chapter 3 'Ensuring Universal Access' (2000). The government is committed to ensure that people living in all parts of the UK, however remote, should have access to television. Serving residents in remote rural areas is expensive and not economically viable for commercial organizations. Universal access to television has so far been achieved through direct government intervention, rather than regulation of market operators. In the telecommunications industry, regulators have instead introduced schemes to give incentives to private providers for universal provision. We refer to Laffont and Tirole (2000) for a discussion of the principles of universal service policies and to Riordan (2002) for a recent review of universal service policies applied to fixed telephony. Sorana (2000) proposes the use of auction mechanisms to determine universal service subsidies. Similar incentive schemes could be used to ensure universal provision of television services through private providers.

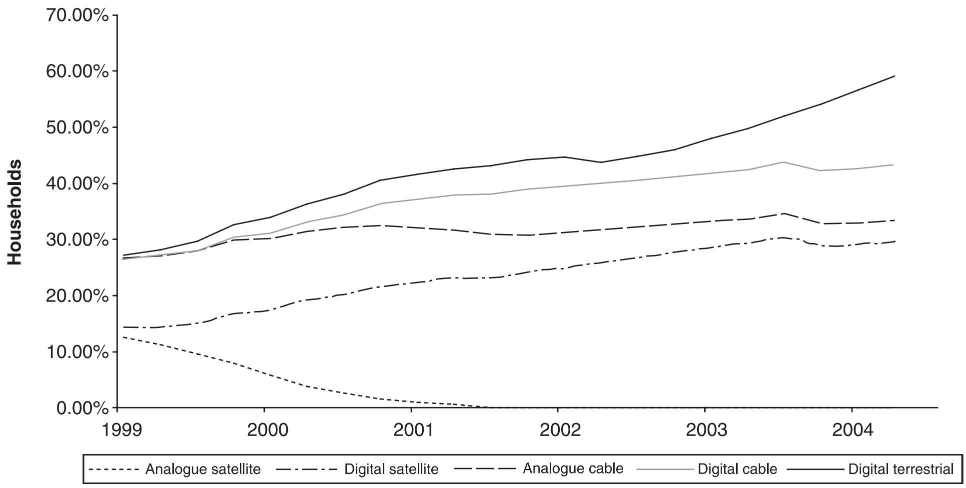

Figure 1. Evolution of multi-channel penetration in the UK

Source: Ofcom (2004).

motives, the purpose of our paper is to develop an analytical framework for the evaluation of the effects of the different policies that are currently under consideration.

2.2.2. Government role for digital transition. It is natural to wonder whether governments should take an active role in the transition to digital, or whether migration to the superior digital technology will take place spontaneously. Why is the transition to digital terrestrial television a public policy problem, compared to other changes in technology standards, such as those used for music records or computer operating systems? We expect governments to take an active role in the transition because of the interplay of two motives, one economic and the other non-economic.

First, digital terrestrial transmission technology uses a publicly owned, rather than a privately provided network. Here the government acts as the 'private' owner of the network, and is interested in solving the co-ordination problem associated with switching standard. The owner of a network has an incentive to internalize the externality associated with adoption by viewers, for example by subsidizing the equipment needed for adoption.[16] Indeed, BSkyB managed to convert its UK satellite network from analogue to digital in the UK within three years, starting in 1998 and finishing in 2001 (cf. Figure 1). BSkyB solved the co-ordination problem by installing the required digital STB free of charge to its existing customers.[17]

Second, most governments perceive the transition to digital television as having important non-economic consequences, due to the social role of the media. According

[16] This is often done by mobile phone operators and pay television networks. Essentially, well-defined property rights on the ownership of the network can alleviate the problem of network externalities.

[17] More broadly, this raises the issue of privatization of the UHF spectrum, discussed above. See also Hazlett (2001) and Cramton *et al.* (1998).

to a widely held view, an increased and more competitive supply of television channels should improve the overall flow of information in the society, with positive economic and political effects.[18] Moreover, fears that a two-tier society (divided by ease of access to information) are also present in public opinion. Operationally, universal access to the traditional FTA channels is seen as a minimal condition to avoid this 'digital divide'. The universality objective implies that switch off of analogue television will not be feasible until almost all viewers have migrated to digital television.

Switching to the digital standard is a public policy problem due to the interplay of the scarcity of available spectrum with the universality requirement. To understand this, note that the policy maker faces a resource constraint because of the limited total amount of available UHF spectrum that can be divided between analogue and digital broadcasting. At each point in time, the total terrestrial spectrum available can be allocated partly to analogue and partly to digital broadcasting, and the number and quality of digital services must be determined.

Until the analogue signal is switched off, only a limited fraction of the population can be covered with DTT and this coverage has reduced power. This means that part of the population will not be able to receive the DTT signal at all, and part of the population will need to upgrade their aerials to pick up the digital signal. This upgrade would not be necessary after switch off.

This means that the full benefits of digital television can only be achieved after the analogue signal has been switched off and the power of the digital signal increased. In the transition stage, viewers have limited incentives to migrate to digital. In addition, if digital broadcasting attracts few viewers content providers have little incentives to make good content available digitally. Digital equipment will also tend to be expensive if demand is low. But until almost all households have converted their equipment, it is not politically feasible to switch off the analogue signal.

Since the spectrum is limited, policy makers face tradeoffs. Holding constant the coverage of analogue and the number of analogue channels, the coverage of digital can be increased only by reducing the number of digital channels. For example, in the UK the current network using 80 transmitters is capable of providing some DTT services to 80% of the population. It is not technically feasible for the entire country to receive DTT unless the analogue signal is switched off in part of the country. This tradeoff varies across countries, depending on their allocation of terrestrial spectrum and the number of existing FTA channels.[19]

In conclusion, the nature of the policy makers' problem is similar to that faced by private operators using other platforms with limited bandwidth, but it is exacerbated

[18] See Anderson and Coate (2001) for a model of television competition in which increased availability of television channels can improve social welfare by reducing the cost of advertising. In a recent empirical paper, Djankov *et al.* (2003) find that concentrated (as well as public) ownership of media tends to be associated with 'bad' social and political outcomes. See Besley and Part (2001) for a study of the effect of media competition on government accountability.

[19] For example, there is more spectrum available for simulcasting in the UK than in Italy, because the UK has only five analogue channels, while Italy's spectrum is clogged up by many more local channels.

by the universality requirement that it is difficult to switch off part of the nation. The political feasibility constraint does not allow governments to commit to a firm switch-off policy. The fact that the switch-off policy must then be conditional on aggregate adoption introduces strategic effects, as explained in Section 5.

It is worth remarking that privatization of the spectrum will not automatically solve this problem, as meeting the universality requirement will still require intervention and regulation. Nevertheless, governments often have conflicting interests in the switchover process, being involved as owner of the spectrum as well as public broadcaster. This might make the co-ordination with commercial broadcasters who operate FTA channels and might lose from the transition to digital television, due to the increased competition with the additional digital channels.

3. EARLY EXPERIENCES

In this section, we discuss the different approaches to digital transition pursued by some of the major Western countries. We study the situation in the UK, France, Germany, Italy and the US. For each country, we give a brief overview of the recent evolution in television markets and an account of the policies for digital switchover.

3.1. The UK

There are five FTA channels, two public channels produced by the British Broadcasting Corporation (BBC) and three commercial channels (ITV, Channel 4 and Channel 5). The BBC is not allowed to advertise, while the commercial channels are subject to content regulation and limits on advertising.

Pay television is currently available through satellite (BSkyB) or cable (NTL and Telewest). From 1998 to 2002, there was also a DTT pay television network operated by ITVDigital, which has now been replaced by an FTA digital platform run by Freeview. The strong initial growth of digital television is in part the result of a move by satellite and cable operators to switch subscribers from analogue to digital packages. By 1998, analogue multi-channel television had already penetrated some 25% of households.

In 1999, the UK government declared its commitment to ensuring that terrestrial analogue broadcasting signals are maintained until the following three criteria are simultaneously satisfied:

- *Availability*. Everyone who can currently get the main public service broadcasting channels in analogue form (BBC 1 and 2, ITV, Channel 4/S4C and Channel 5) can receive them on digital systems.
- *Affordability*. Switching to digital is an affordable option for the vast majority of people.
- *Accessibility*. As a target indicator of affordability, 95% of consumers have access to digital equipment.

Box 1. From the ITVDigital debacle to Freeview

OnDigital (later renamed ITVDigital) was launched in November 1998 as the first DTT broadcaster in Europe. The licence for DTT broadcasting was won by a partnership between Granada and Carlton (the ITV operators) and BSkyB. However, BSkyB was forced out by competition concerns in 1997 and had no choice but to compete against the new DTT operator. Indeed, in October 1998, BSkyB began digitalizing its analogue satellite network and distributing free set-top boxes. Fierce competition for exclusive rights for premium content also ensued. While BSkyB won the competition for Premier League rights,* ITVDigital secured the rights for First Division games. Eventually, ITVDigital lost the battle and went bankrupt, at a major loss to creditors and shareholders.

Following the bankruptcy of ITVDigital in the Spring of 2002, the three multiplexes for transmission of digital terrestrial television previously used by ITVDigital were awarded to Freeview. The BBC, Crown Castle and BSkyB are equal partners in DTV Services Ltd, the company formed to provide consumer and retailer support for Freeview. On 30 October 2002, Freeview launched its free digital terrestrial television (DTT) service consisting of some 30 channels and 19 radio stations. In addition to the five free-to-air terrestrial channels, viewers can receive additional BBC digital channels (such as BBC Three, BBC Four, CBeeBies, BBC News 24) and other basic channels (such as UK History, Sky News, Sky Sports News and Sky Travel) as well as text and a range of interactive services.

Retailers struggled to keep up with demand for STBs for Christmas 2002 and many shops sold out of boxes. Nevertheless, critics of Freeview have maintained that the growth in this platform would level off once the initial demand had subsided.

* Payments for the right to broadcast the UK's Premier League live soccer games have increased drastically over time. Until 1992, BBC and ITV acted collusively, obtaining the rights for a yearly payment of roughly £3 million. BSkyB obtained the rights for a yearly payment of roughly £37 million in 1992, £167 million per year in 1997, and £366.6 million per year in 2000. BSkyB has so far always acquired these rights under exclusive vertical contracts and has been selling the resulting premium programming directly to its subscribers. BSkyB has also been selling premium programmes indirectly to the subscribers of the competing pay TV companies in exchange for payments of per-subscriber monthly fees. See Cave and Crandall (2001) for a recent account of the role of sports rights in the broadcast industry.

The UK government initially expected that these targets would be met sometime in the period 2006–10. The BBC has suggested that 2012 may be the most appropriate date for the completion of switchover.

3.2. Germany

In Germany, as in other countries in central, northern and eastern Europe as well as in the US, terrestrial television broadcasting is a niche market. Since most German

Box 2. The Berlin switch

Berlin was the first jurisdiction to switch off the analogue terrestrial signal, in August 2003 (see Wagner and Grünwald, 2003a; Hazlett, 2003). Before the 'Berlin switch', the great majority of the 1.8 million TV households in the Berlin-Brandenburg area subscribed to cable or satellite television. Only 160,000 were relying exclusively on analogue reception and so had to choose between purchasing a set-top box to receive digital TV signals over the air or signing up for cable or satellite television.

The Berlin-Brandenburg Media Authority (MABB) co-ordinated the switch off process by setting up a transition scheme through an agreement with the public broadcasters (ARD, ORB, SFB and ZDF), the main commercial broadcasters (ProSiebenSAT.1 Media AG and RTL Television) and the terrestrial network operator (Deutsche Telekom).

In the transition phase, some of the analogue channels were switched off and the spectrum saved was used for digital broadcasting.

The switchover process was accompanied by an information and advertising campaign, at a cost of less than €1.2 million. According to press reports, a competitive market for STBs swiftly developed, with retail prices starting at around €100.

In order not to exclude low-income families from access to television, the government paid for STBs for some 6,000 families that were eligible for welfare benefits and were not subscribed to either cable or satellite digital networks. A budget of €1 million was set aside for this subsidy.

As a result of the switchover, the number of channels available has increased dramatically (27 digital channels now exist in lieu of 12 analogue ones) and significantly less spectrum is used (the 27 digital channels occupy the same amount of spectrum as just 7 of the old channels). The federal states of Saxony, Saxony-Anhalt, Thuringia and North Rhine-Westphalia are expected to be following in Berlin's footsteps soon.

households currently subscribe to cable or satellite, the switch off of the analogue terrestrial signal affects only 3 million households (out of a total of 34 million TV households) receiving television through this platform.

In addition, television frequencies are controlled at the state rather than the federal level. Because of this, the country's approach to switchover is regional and has concentrated on the most populous areas. The intention is to switch off all analogue transmitters in each area after a brief period of simulcasting. Following the trial experience in the Berlin-Brandenburg area, the switch to digital is currently underway in several other regions in Germany.

3.3. France

France remains a terrestrial country, with some 67% of households still on analogue terrestrial in 2002. There are five FTA channels, of which three are government owned and two commercial. A peculiar feature of France is the availability of a pay television channel (Canal+) on the analogue terrestrial platform. In addition, there are two satellite operators (Canal Satellite and TPS) serving 20.5% of the television population. The cable sector is weak and quite fragmented and is losing ground to satellite.

3.4. Italy

FTA television in Italy is essentially a duopoly, with three channels provided by the government-owned broadcasters RAI, and three channels by the private group Mediaset. Cable and satellite have limited penetration, but following a recent merger the satellite operator (Sky) is now gaining market share.

Box 3. The French beauty contest

Digital terrestrial television is expected to be launched soon in France. The 33 DTT channels have already been allocated. The existing three analogue commercial channels have been assigned two DTT channels each (one to broadcast the original channel and another for a new channel), while eight channels have been reserved for the public broadcasting and local television. In October 2002, the French regulatory agency, the Conseil Supérieur de l'Audiovisuel (CSA) allocated the remaining channels for 10 years via a beauty contest. Some of the licensees are supported by advertising and others are pay channels (Bourreau, 2004). The question of who will operate the pay platform has not yet been settled.

Box 4. The Gasparri Bill

According to a new controversial media bill, 'Legge Gasparri', Italy intends to switch off the analogue terrestrial signal by the end of 2006. The government allocated €130 million in the 2004 Budget to support DTT by subsidizing the purchase of digital reception equipment, to a limit of €150 per person. A similar provision was contained in the previous year's budget legislation, but the subsidies were not used because STBs were not available on the retail market.

3.5. The US

Out of a total of 106 million TV households in the US, only 10 million currently receive exclusively FTA terrestrial television.[20] Some of these households are in remote areas, making the transition to digital television a difficult social and political problem.

In contrast to Europe, the US government has only limited involvement in television production. Unlike in most other countries, terrestrial broadcasting is organized around local stations in the US. Each station is allocated 6 MHz of bandwidth – necessary in order to analogically broadcast a channel using the American standard system for colour television (NTSC).

The Telecommunications Act of 1996 established the framework for licensing terrestrial spectrum for digital broadcasting and set a target transition deadline of 31 December 2006. Existing broadcasters retained their original 6 MHz channel for analogue broadcasting until the expected completion of the transition and were assigned an additional 6 MHz channel to facilitate the switchover.

The Balanced Budget Act of 1997 specified that broadcasters could keep their analogue television service beyond 1996 if fewer than 85% of the television households in their market were able to receive digital signals (either off the air or through cable). Due to the reliance of the '85% rule' on consumer demand for digital equipment, delays are expected in the return of the spectrum.

It is believed that most Americans have little incentive to buy digital reception equipment for terrestrial television, due to the limited number of channels available. In turn, terrestrial broadcasters do not have much interest in investing in digital transmission due to lack of viewers. Because so few consumers have purchased digital tuners, many commentators expect that the 2006 deadline will not be met.

[20] See Levy *et al.* (2002) for an overview of the US market, Farrell and Shapiro (1992) on standard setting and adoption, Goolsbee and Petrin (2003) on the advent of satellite television, and Hazlett (2001) on the transition to digital television.

Box 5. The US digital tuner mandate

In August 2002, the Federal Communications Commission (FCC) ordered that from 1 July 2007, all television receivers with screen sizes larger than 13 inches and all television receiving equipment, such as VCRs and DVD players and recorders, must have digital reception capability. It set out a five-year roll out scheme starting with larger receivers, for which the first deadline is 1 July 2004. Critics of this policy argue that TV viewers subscribing to cable or satellite do not need digital tuners, but will be forced to bear this extra cost.

4. MODEL

Before we plunge into the model, consider the highly simplified set up given in Box 6.

In this section we give an informal presentation of our model. The reader interested in a full description can consult the appendix.

The model focuses on the demand side of the television market. Our unit of analysis is the individual household (referred as 'viewer'), who decides over time which television platform and package to adopt. The model is designed to forecast the evolution of market shares of different platforms, for given prices and characteristics of television packages. These supply-side parameters are treated as parameters of the model.

The model allows for the supply-side parameters to change over time, before the analogue terrestrial signal is switched off. The model is designed to enable supply-side players to assess the effect of their actions on viewers' decisions. This is done by simulating the model for different parameter values (Section 5).

In reality, supply-side conditions are the result of the actions taken by policy makers and competing platform operators. In our model, we do explicitly account for the feedback of market adoption on supply-side behaviour.[21]

4.1. Theory

We restrict our attention to the choice of platform and package of channels for the primary television set by viewers. The model is in discrete time, and each period lasts one year.

4.1.1. Preferences for packages. In each period of time, each viewer who is *already* connected to a television platform can choose a package of television channels

[21] By adding information on the cost structure of platform operators, the model can be extended to allow for endogenous supply-side behaviour. This can be done by following the same methodology we have adopted to endogenize the cost of DTT STBs. See also our discussion of policy scenario 7 in Section 5. We also assume away network externalities. See Farrell and Shapiro (1992) and Auriol and Benaim (2000) on strategic adoption incentives with network externalities, absent in our model.

Box 6. Viewers' types and expectations

Focus on a viewer who currently has access to analogue television and is considering whether to adopt digital television. There are two periods, today ($t = 1$) and tomorrow ($t = 2$), with discount factor β.

Let v_A be the utility derived from analogue television in the first period, net of the television licence fee. Similarly, let v_D be the period 1 utility from digital television (net of subscription charge) and C be the cost of a STB. Denote by D the second-period continuation value for a viewer who is able to see digital television, by A the continuation value for a viewer who is able to see analogue television only, and by N the continuation value for a viewer unable to see television (e.g., because the analogue signal has been switched off in period 2). Note that analogue viewers satisfy $v_A + \beta A > v_A + \beta N$, by revealed preferences.

Is it useful to distinguish three types of viewers:

- The 'enthusiasts', who prefer to adopt digital television rather than sticking with analogue television. Their preference parameters are such that $v_D + \beta D - C > v_A + \beta A$.
- The 'traditionalists', who prefer not to adopt digital television if they can keep receiving the analogue signal, but prefer digital to no television. Their preferences satisfy $v_A + \beta A > v_D + \beta D - C > v_A + \beta N$.
- The 'troglodytes', who prefer to forgo viewing television altogether rather than adopting digital television, i.e., $v_A + \beta N > v_D + \beta D - C$.

Clearly, the enthusiasts will adopt digital television unambiguously, while the troglodytes will never adopt digital. The traditionalists instead will go digital if and only if their alternative to digital is no television. This means that the decision of the traditionalists depend on their expectations about switch off. Therefore, it is important to allow for expectations for switch off when modelling individual digital adoption decisions.

among those offered on that platform. The decisions depend on prices and the characteristics of the packages. The price of package j is denoted by p^j and its vector of characteristics by X^j. These characteristics include the delivery platform, the number of channels available and the presence of premium content.

The viewer's utility from package j in a period is specified to be

$$u(j, p, X) = \alpha X^j - \gamma p^j + \eta^j, \tag{1}$$

where j is the index of the platform and η^j is a preference shock. To ease the computational burden, we assume that this shock follows an extreme value distribution with mean zero and variance 1 (cf. McFadden, 2001, and references therein).

We allow for heterogeneity in the viewers' preferences for money (γ) and characteristics (α), depending on their observed individual characteristics such as the household size, household income or the age of the head of household. Since the problem is separable across viewers, we consider each viewer's problem in isolation and then obtain aggregate predictions by summing over the decisions of all viewers.

4.1.2. Switching costs. At the *beginning* of each period, the viewer has the option of changing platform, but doing so involves the payment of a fixed 'switching' cost. This cost has two components. First, there is a 'psychological' cost of changing platform, due to the inconvenience and time needed. Second, there is a 'physical' cost related to the fixed cost of the new equipment (set-top box, satellite dish, aerial or rewiring) needed to connect with the new platform.

We posit that the cost of terrestrial set-top boxes depends on its cumulative adoption, according to a simple 'learning curve' relationship. As explained in the appendix, the cost of a DTT STB (C_t) goes down by a fixed percentage (the 'learning rate') $r = 1 - 2^b$ as cumulative output (Q_t) doubles, where b satisfies

$$\ln C = \ln a + b \ln Q. \tag{2}$$

Since the quantity of DTT STBs is an outcome of our model, the cost of DTT STBs is therefore determined as part of the model's solution.

4.1.3. Information. The viewers are assumed to *expect* that the analogue signal will be switched off at a certain future period. By treating the expected switch-off date as a parameter of our model, we can understand the role of expectations for take up of digital television.

For consistency and simplicity, we assume that all the parameters of the model and the equilibrium are common knowledge among the viewers.

4.1.4. Choice. Each viewer's decision is inherently dynamic, because it involves the comparison of the one-off switching cost with the flow of associated future net benefits. The state variable of each viewer's dynamic problem is the television platform and package adopted by the household in the previous period. In each period, viewers maximize the flow of current and future utility by choosing the optimal platform to watch, conditional on preferences, platform characteristics, current and future prices, costs and expected switch-off date.

The model distinguishes two phases, a first phase before switch off and a second after switch off. During the 'pre-switch' phase, the consumer has access to all television platforms, although the viewers know that the analogue signal will be switched off at some point in time. The model allows the model's parameters (prices and package/platform characteristics, resulting from market and policy conditions) to vary from period to period during this first transition phase.

In the 'post-switch' phase, viewers do not have access to analogue terrestrial television any more. We assume that all the parameters of the model are constant during this second phase.

4.2. Estimation

We have calibrated the preferences for characteristics of television packages (platform, number of channels, and availability of premium) from the estimates based on a market research survey. We have estimated the relationship between production cost for the set-top box and number sold from a short time series. In this section, we outline our estimation procedure.

4.2.1. Viewers' preferences. We have calibrated the model using survey data with stated preferences for television by UK consumers. The data set is the Survey of Television undertaken for the Radiocommunications Agency by Steer Davies Gleave, reporting the choice of 448 individuals confronted with 20 different hypothetical choice scenarios. In each choice scenario, the individual had to take one of two options. The first option was always analogue terrestrial FTA and involved no extra cost, in addition to the licence fee that must be paid in order to receive television. The second option always involved multi-channel television. The second option was different in each of the 20 scenarios, with variation in the delivery platform (terrestrial, cable or satellite), number of channels, availability of premium content, monthly subscription fees and initial costs.

Table 3 provides a description of the data set. The data set reports each time the choice and the characteristics of all platforms involved in the choice set. In addition, the data reports socio-economic characteristics of the individuals interviewed, such as family structure or income levels. In total, we have 16,010 valid observations.

We use these stated preferences to identify the per-period utility function, as explained in the appendix. We use the variation in prices, product and individual characteristics to estimate the parameters (α and γ) of the utility function (1) by maximum likelihood. Table 4 reports the parameter estimates for the whole sample. Individuals are price sensitive, and value the number of channels and premium contents.

For the purpose of the calibration of our model, we segment our data set along a number of observed socio-economic characteristics of the viewers. In particular, for illustrative purposes we have broken up the data along three dimensions:

- Income, with three groups: low household income, with less than £15,000 per year; medium, with income in the bracket £15,000–£30,000; and high, with more than £30,000.
- Age, with two groups: head of household younger or older than 40.
- Household size, with two groups: small or large with strictly more than two individuals in the household.

Table 3. Descriptive statistics

Platform characteristics		
Number of cards shown		20
Number of alternatives per card		2
Subscription price	Analogue	0 (0)
	Alternative	£33.4 (23.7)
Installation cost	Analogue	0 (0)
	Alternative	£168 (203)
Number of channels	Analogue	5 (0)
	Alternative	28.3 (44.8)
Digital	Analogue	0 (0)
	Alternative	32% (47)
Premium content	Analogue	0 (0)
	Alternative	20% (40)
Individual characteristics		
Number of individuals in survey		448
Proportion age above 40		44.5%
Proportion household with more than 2 members		49.1%
Household income	Below £15,000	28.7%
	In £15,000–£30,000 range	41.6%
	Above £30,000	29.7%

Notes: Each card contained two alternatives. One alternative was always analogue FTA and the second alternative was one of the following three: DTT, cable or satellite. Standard deviation in parentheses where appropriate.

Source: Our analysis of data from the Survey of Television undertaken by Steer Davies Gleave in 2003.

Table 4. Parameters of utility function at mean sample

	Coefficient	Standard error
Monthly cost	−0.020**	0.001
Log channels	0.14**	0.03
Digital	−0.18**	0.08
Premium content	0.28**	0.1
High definition television	−0.05	0.1

Notes: Regression done on 16,010 observations. Pseudo R-squared: 0.11. The dependent variable is an indicator (0/1) variable reflecting the choice of a given platform. The table reports the coefficients of a fixed effect logistic regression model, where we allow for an unobserved individual taste. The regression also controlled for interactivity features such as choosing the camera angle or online gaming which also characterized some of the platforms as well as installation costs. Statistical significance: * and ** respectively for 5% and 1% level (two-sided test).

Source: Our analysis of data from the Survey of Television undertaken by Steer Davies Gleave in 2003.

In total, we have 12 different segments.

For each segment of the market, we estimate a specific set of coefficients for the utility function. To save space, we do not report all the coefficients for all segments. Figure 2 illustrates the heterogeneity in the marginal utility of the (logarithm of the) number of channels. Young households with children value highly platforms with many channels. Interestingly, young small households have more interest in television

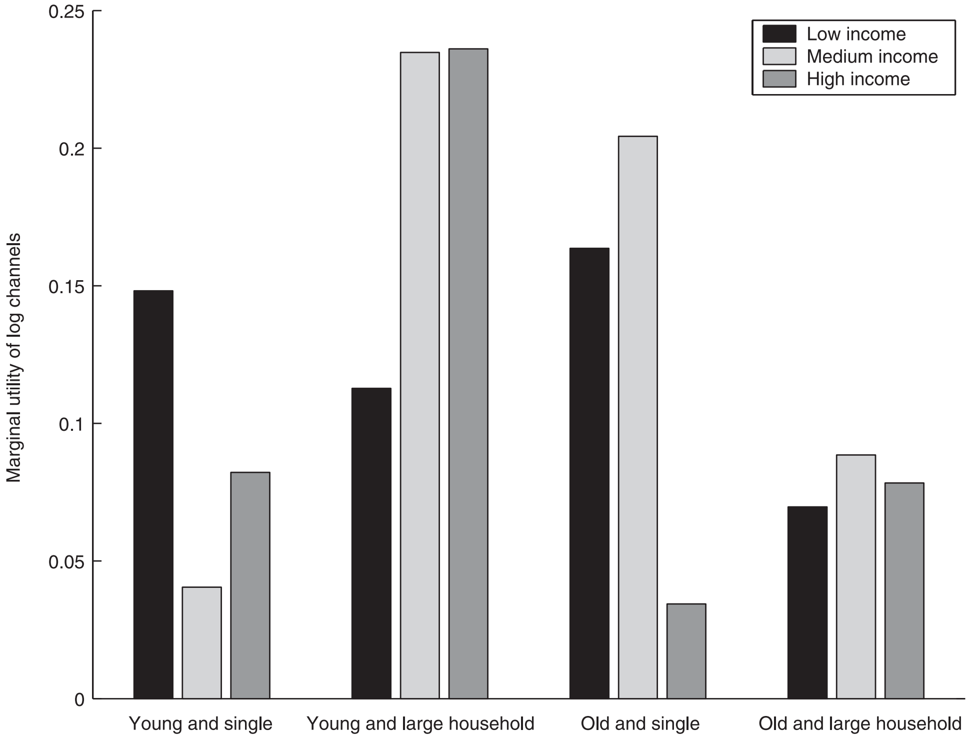

Figure 2. Marginal utility for channels depending on household characteristics

channels when they have lower income. Old households at the top of the income distribution have very limited interest in the number of channels. Similar heterogeneity is found for the other parameters. Due to this heterogeneity in preferences, we expect viewers to adopt different platforms over time and be differently affected by policy.

4.2.2. Terrestrial set-top box prices. To estimate the 'learning rate' at which the cost of DTT STBs decreases with the total units sold, we use time series data on set-top box prices and quantity sold.

We have obtained the prices of different models of set-top boxes from idtv.co.uk for 5 months in the years 2003–2004. For each of these months we have computed the average price for the 11 models for which we have prices in all 5 months.[22] Overall, the average price of a set-top box fell from £120.58 in January 2003 to £77.26 in July 2004. We have constructed the data on quantity of set top boxes installed overall in the UK in each of these months by interpolating the quarterly take up of DTT, obtained from Ofcom's publications.

[22] Over time, there is a marked increase in the number of available set-top boxes. As the market matures, two phenomena can be observed. First, many more products are sold at low prices. Second, more products with added features are introduced at the high end of the spectrum. Overall, the trend of the average price is robust to the introduction of new products.

Estimation of equation (2) by ordinary least squares gives $b = -0.313$ with standard error 0.038. This means that the average cost decrease by 0.313% for every 1% increase in cumulative output, so that the cost of producing one unit goes down by roughly 19.5% as cumulative output doubles.

4.3. Simulation

Given the calibrated parameters, the model determines the dynamic behaviour of each type of household, before and after the switch from analogue to digital. The model is solved numerically, as explained in detail in the appendix. For each period, we compute the market share of each platform for each segment of the population, by summing across the packages corresponding to that platform. We then aggregate across population segments to obtain the fraction of the population that adopts each platform.

4.3.1. Baseline parameters. In order to simulate the model, we need to specify a number of parameters. For each package offer and for each period we need to specify subscription prices, installation costs, and quality characteristics (platform, coverage, number of channels, availability of premium content).

Our baseline scenario corresponds to a stationary 'policy off' scenario. Therefore, we have assumed that the subscription prices are constant across all periods. In addition, we set the yearly discount factor at a conventional value of 0.95.

As shown in Table 5, the parameters are set at values corresponding to the conditions of the UK market in 2001–2002 when ITVDigital went bankrupt and Freeview was introduced. We assume that DTT Freeview is available with 20 channels, but that no premium DTT is available.

The initial conditions of the market shares in period 1 are set to match the historical shares for 2001, provided by Ofcom (2004). In order to calibrate the costs of switching from one platform to another, we use observed monetary costs (i.e. the average price of a set-top box or a satellite dish) to which we add a 'psychological' switching cost calibrated by matching the market shares in period 2 with observed market shares in 2002.

In the baseline scenario, people do not expect the analogue switch off to take place in the foreseeable future.[23]

4.3.2. Baseline results. Figure 3 displays the market shares for analogue, DTT, cable and satellite for our baseline scenario. DTT increases from about 5% to 13%. The shares of cable and satellite increase respectively by 10% and 20%. Analogue goes from initial share of 58% to 18%. For each of the market shares, we also display

[23] This is implemented numerically by setting the expected switch-off date at a distant future period.

Table 5. Parameters for baseline scenario

Parameter	Value
Price of analogue TV set	£100
Price of aerial	£150
Cost of satellite dish	£55
Cost of wiring house for cable	£25
Fraction of households covered by DTT	0.75
Fraction of households covered by cable	0.5
Number of FTA analogue channels	5
Number of FTA DTT channels	25
Number of FTA satellite channels	25
Number of basic satellite channels	95
Number of premium satellite channels	105
Number of FTA cable channels	20
Number of basic cable channels	47
Number of premium cable channels	88
Subscription price of analogue	£0
Subscription price of DTT FTA	£0
Subscription price DTT premium	£10
Subscription price of cable FTA	£10
Subscription price of cable basic	£16
Subscription price of cable premium	£35
Subscription price of satellite FTA	£15
Subscription price of satellite basic	£20
Subscription price of satellite premium	£35
Licence fee for TV	£9
Availability dummy for premium on DTT	0

Notes: Subscription prices and licence fees are monthly.

the 95% confidence bands.[24] According to the learning curve, the endogenous price of a set-top box declines from £100 to £60 over 10 years.

5. POLICY ANALYSIS

How do different policies affect the take up of DTT? What impact do they have on the other platforms? What is the effect on consumer surplus? We can address these questions by comparing the predictions of our model for different parameter values.

5.1. Comparison of scenarios

In this section, we compare the adoption paths for analogue, DTT, cable and satellite in the baseline scenario with those resulting in seven hypothetical policy scenarios in Figures 4–9. We then compute the impact of these policies on consumer surplus, as summarized in Table 6.

[24] These confidence bands have been computed by Monte Carlo simulations, draws 100 times the parameters for the consumer preferences from the distribution estimated from our survey data.

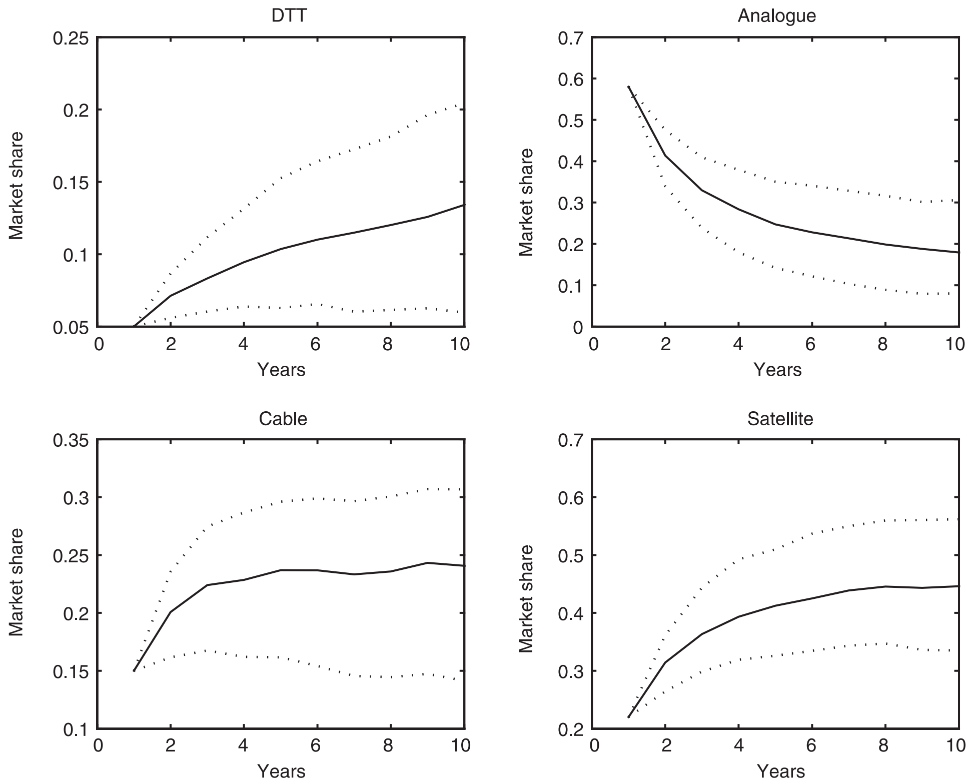

Figure 3. Evolution of adoption of different platforms for the baseline scenario (Scenario 1)

Note: The dotted lines give the 95% confidence bands.

5.1.1. Increase in DTT channels (Scenario 2). We begin by considering the effect of an increase in the number of channels available on DTT from 20 (baseline) to 30 from period 3 onwards. This policy is inspired by the increase in the number of channels available on the DTT platform in the UK. As illustrated in Figure 4, this policy increases the market share of DTT, which reaches 18% after 10 years. The effect on analogue is small, although some viewers switch to DTT. In fact, most of the increase in DTT comes from cable and satellite.

5.1.2. Increase in DTT Coverage (Scenario 3). Next, we consider the effect of an increase in the coverage of DTT, illustrated in Figure 5. The coverage is progressively extended, from 70% of the population to 95% in period 8. The result is an increase in the DTT market share of about 3%. The increase comes from a decrease in the market shares of satellite and cable.

5.1.3. Introduction of premium content on DTT (Scenario 4). We then turn to the effect of the introduction of premium content on DTT, as currently debated

Table 6. Policy experiments and effects on consumer welfare

Scenario	Policy	Description	Impact on consumer surplus (£ million)
1	Baseline	See Table 5 for description	
2	Increased number of DTT channels	Number of DTT channels is increased from 20 to 30 from year 3	+194
3	Increased coverage of DTT	DTT coverage is increased from 75% of population to 95% from year 5	+134
4	Availability of premium DTT	DTT premium is made available (at £10 per month) from year 3	+380
5	Rapid switch off	Analogue switch off is expected to happen in year 10, when DTT coverage is increased to 100% and number of DTT channels from 20 to 40	−2,017
6	Subsidies to DTT equipment	Subsidies to set-top boxes are given to poorer households in year 3 only	+5
7	Free basic satellite	Free basic satellite is available from period 5	+2,049

Notes: The aggregate consumer surplus in each scenario is obtained by computing the weighted average in the population of the value function (in period 1) of each household type obtained from our calibrated choice model. The effect of each policy on consumer surplus is equal to the difference in the aggregate consumer surplus under the corresponding scenario with the baseline scenario.

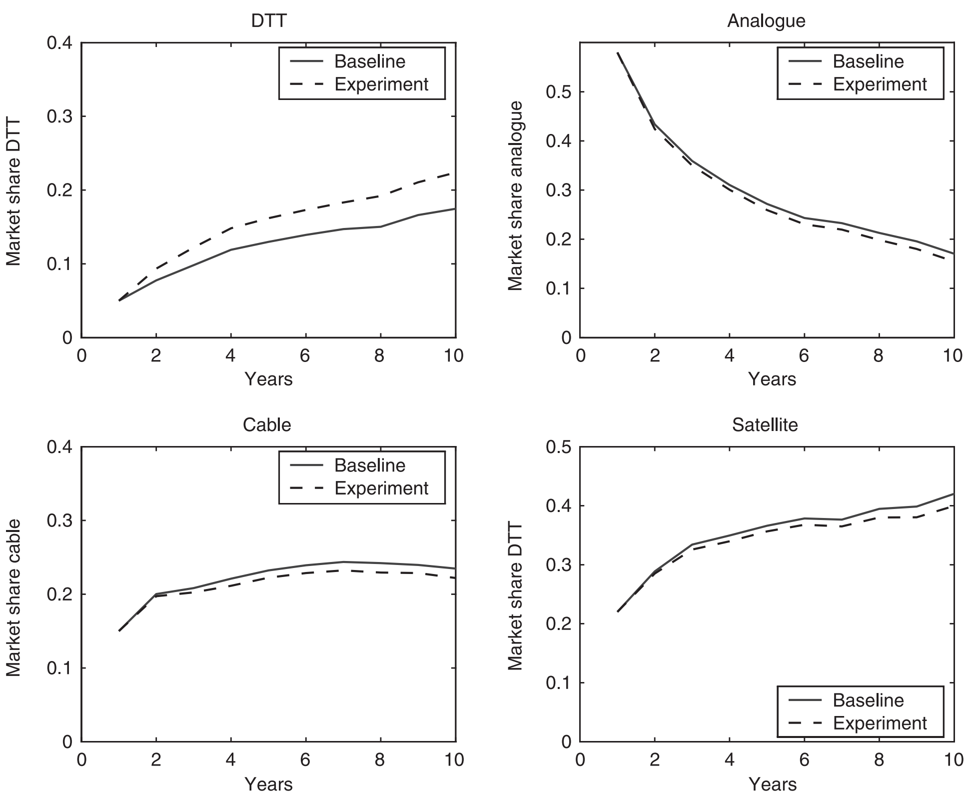

Figure 4. Effect of increased quality of DTT (Scenario 2)

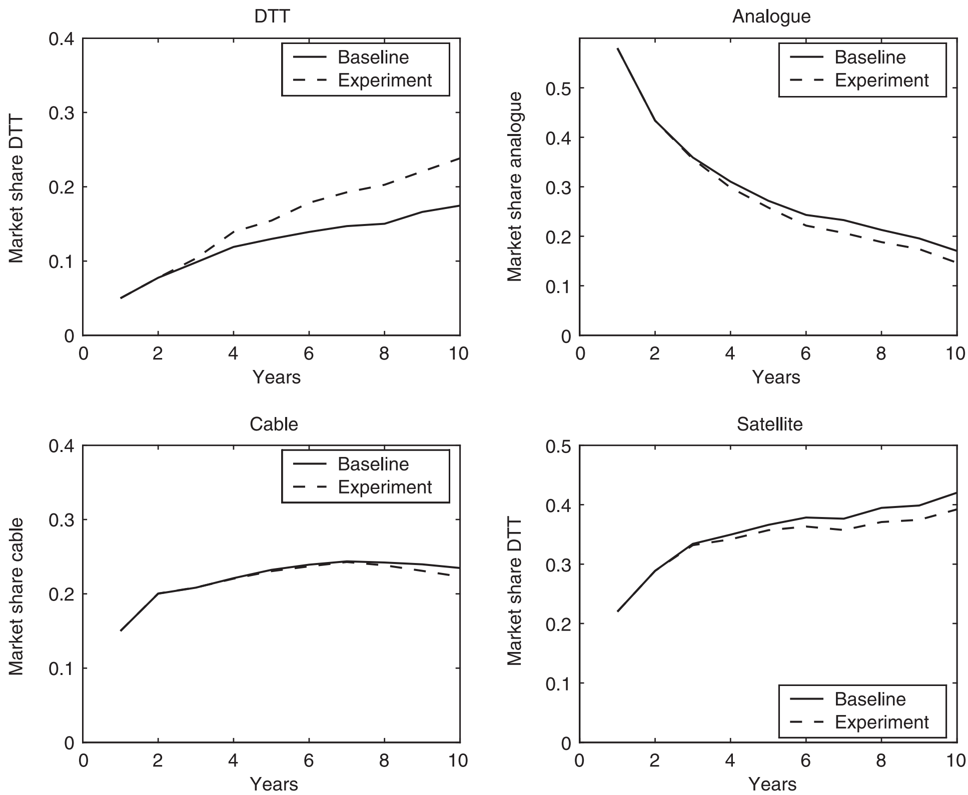

Figure 5. Effect of increased coverage of DTT (Scenario 3)

in France and recently introduced in the UK. As shown in Figure 6, the market share of DTT increases by about 15% at the expense of all other platforms.

5.1.4. Firm commitment to early switch off (Scenario 5). As discussed above, a firm switch-off date has been adopted in Berlin. Figure 7 illustrates what happens when viewers expect that there will be a firm switch off in period 10. We assume that after switch off 95% of the population has access to DTT, so that there are benefits in terms of increased coverage of DTT.

We find that this policy has a major effect on all platforms. The share of analogue falls to zero in the last period, the DTT platform gains a substantive market share over time. Intuitively, DTT is the closest substitute to analogue, and the occurrence of the switch off results in a major increase in the value of DTT. We estimate that less than 3% of viewers opt out of television.

The simulation shows that almost all households adopt digital technology by the switch-off date, if they expect switch off to be inevitable at that date. This is due to the fact that households have a very strong preference for television. As a consequence, very few households will decide to opt out of television to save the cost of the digital equipment.

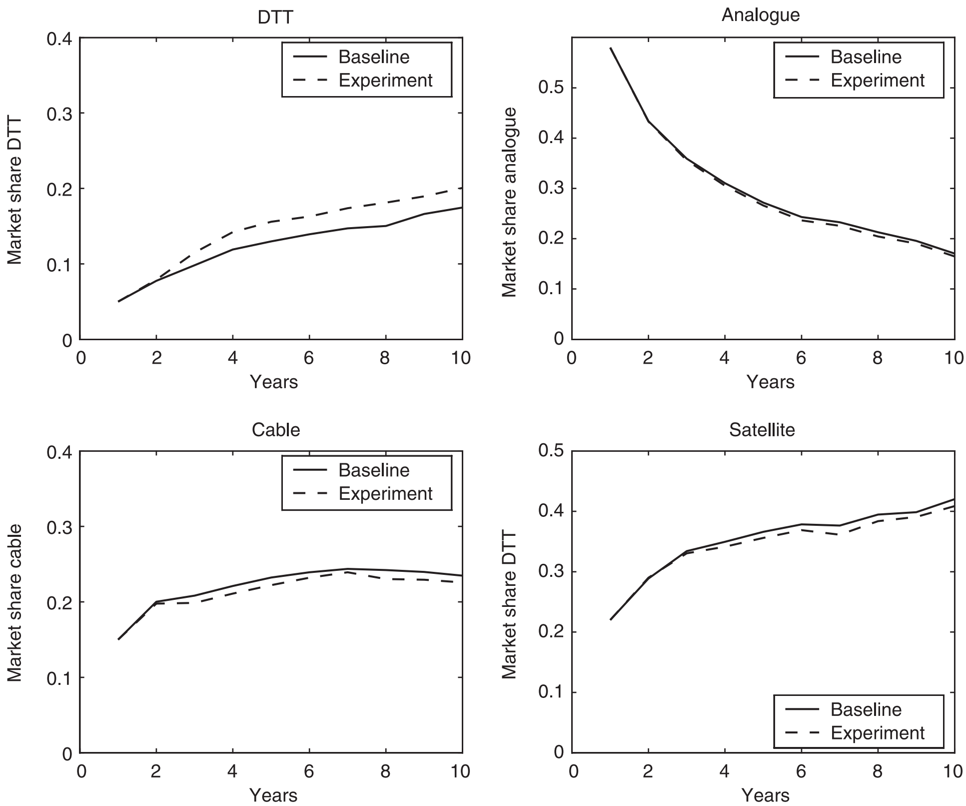

Figure 6. Effect of premium availability on DTT (Scenario 4)

5.1.4.1. Committed versus conditional switch off. Consumers' expectations are important for the success of switch-off policies. There are two possible forms of announcements of a switch-off date, with different effects on the agents' beliefs. First, there could be an irrevocable *commitment* to a firm switch-off date, regardless of digital take up. Second, the policy maker could announce a *conditional* switch-off policy, specifying certain criteria for take-up to be satisfied before switch off.

For an example of a conditional policy, the government could announce that it intends to switch off the analogue signal in period 10 provided that at that date '95% of consumers have access to digital equipment'. In the corresponding commitment policy, the government would instead state that it expects the same criterion to be satisfied upon switch off, but that switch off will take place regardless of whether the criterion is met or not.

These two different policies have potentially very different effects. As illustrated in scenario 5, the policy maker's commitment to a firm switch off in period 10 is clearly credible. A conditional switch-off announcement can instead result in multiple equilibrium outcomes. In order to verify this last claim, we now show that different beliefs of consumers induce adoption paths compatible with those beliefs.

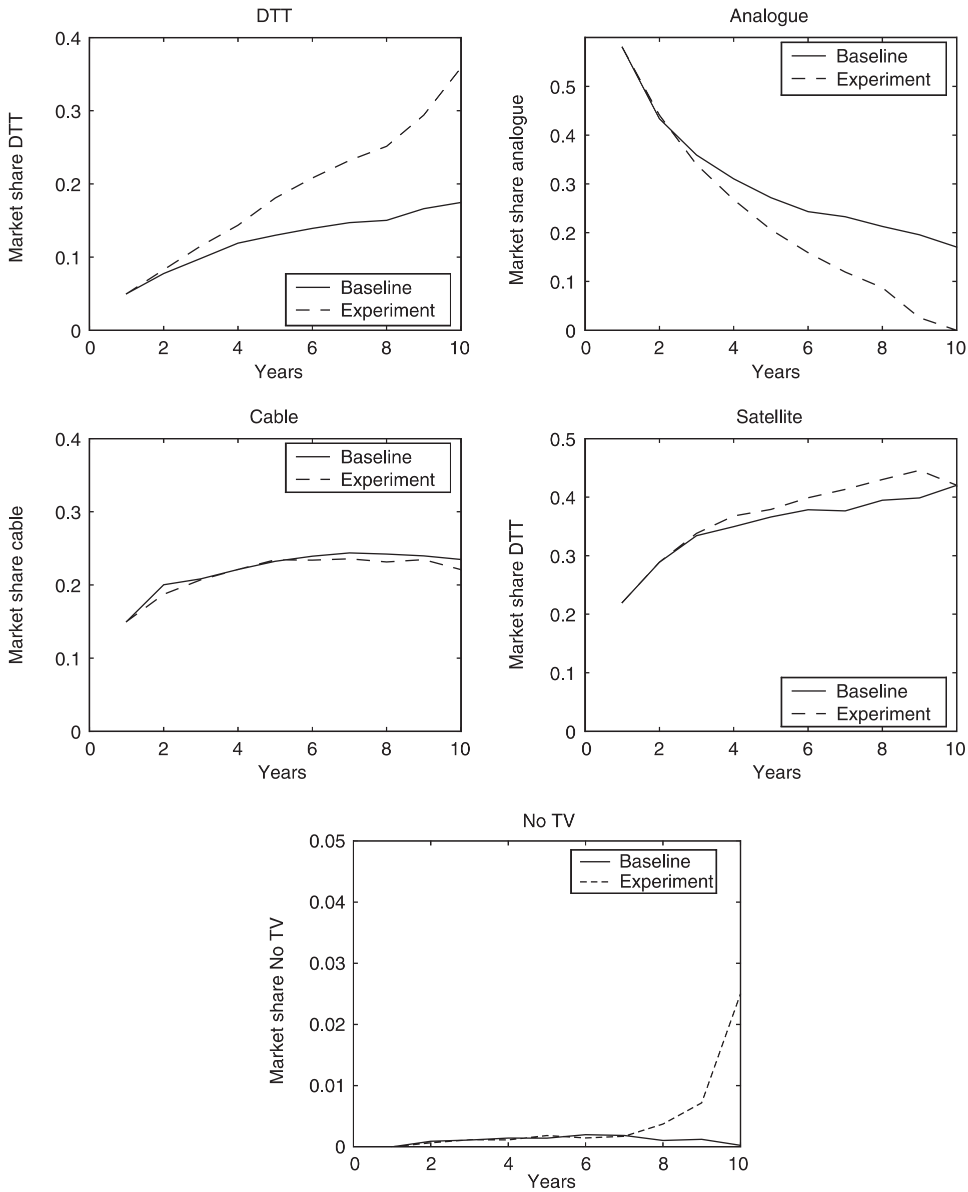

Figure 7. Effect of expectation of an early switch off (Scenario 5)

Suppose that the government were to announce that analogue switch off will take place in period 10 and that switch off would only be delayed if at switch off more than 5% of the households have not yet migrated to digital for their main TV set. There are then (at least) two equilibria.

In a ‘switch’ equilibrium, households expect that switch off will take place by the announced switch off date, exactly as in the case of a firm commitment. This corresponds to scenario 5. Given this expectation, most households will adopt before the

Box 7. Multiple equilibria with conditional switch off

To understand the importance of expectations for the individual decision of whether to convert or not to digital television, consider the simple model formulated in Box 6. In the population there is a fraction σ of 'traditionalists' and τ of 'troglodytes'.

Suppose that the government announces switch off if at least 95% of the population had switched to digital by period 2. Clearly, if there are many troglodytes ($\tau > 5\%$), there will be no switch off. Given the estimated preferences this case is most unlikely.

If there are few troglodytes ($\tau < 5\%$) but many traditionalists (so that $\sigma + \tau > 5\%$), then the expectations of the traditionalists will make a difference. Clearly, if the traditionalists believe that the switch-off criteria will be met, they will adopt and so the criteria will be met. But some of the traditionalists could join forces with the troglodytes and become 'refuseniks'. Indeed, if a large enough fraction of traditionalists believe that the switch-off criteria are not going to be met, they will not adopt and so the criteria will actually not be met and there will be no switch off!

announced switch-off date. As a result, the condition for switch off will be satisfied at the switch-off date and switch off will take place.

But there is also a 'no switch' equilibrium in which households expect that the conditions for switch off will not be met at the announced date. Given that households expect that the analogue signal will not be switched off in the foreseeable future, we are back to our baseline scenario. There, at least 5% of households will still be with analogue technology in period 10.

More generally, by simulating our model we can also show that if the governments were to announce a switch off in period 11, this could be credibly achieved. Multiplicity of equilibria is driven by the fact that there are very few viewers who prefer to give up television rather than go digital, but enough viewers that adopt only if they expect the signal to be switched off.

5.1.5. Subsidy to DTT STB for low-income households (Scenario 6). Subsidies have been given to low-income households in Berlin. Figure 8 plots the effect of a one-off subsidy for set-top boxes for terrestrial reception for poorer households (with annual income less than £30,000) implemented in period 3. This subsidy is equal to the retail price of the STB. The effect is a modest increase in the DTT market share, with a modest decrease in the market share of analogue. Note that this subsidy is biased in favour of the terrestrial platform.

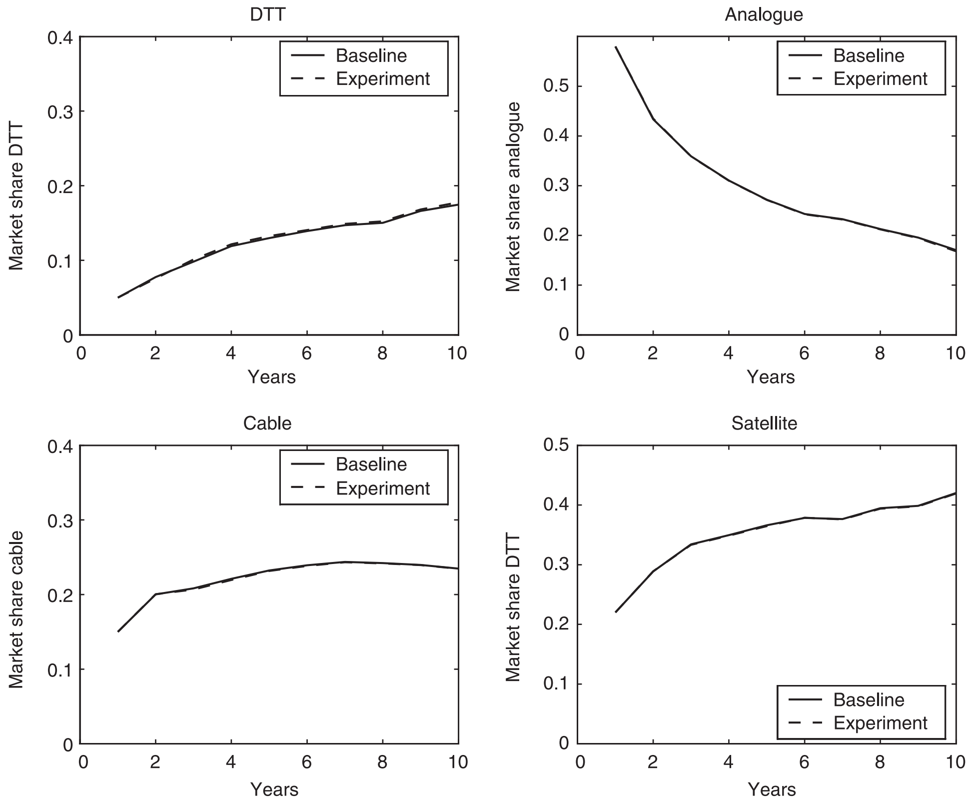

Figure 8. Effect of subsidy to DTT equipment (Scenario 6)

5.1.6. Subsidy to all STB to low-income households. Finally, we have considered a platform-neutral subsidy offered towards the digital equipment that can be used on any platform. Households can also receive the same amount of money towards the purchase of equipment for cable or satellite. The measure is still directed towards poorer households. The results are very similar to those obtained in the previous case, and so the results are omitted.

5.1.7. Satellite offers a free 'basic' package (Scenario 7). We consider what happens if the satellite platform offers its basic package (97 channels) for zero subscription fee. This new package is introduced in period 5, where the subscription price goes from £16 to zero.[25]

The effect is a sharp rise in the market share of satellite and a marked decline in the shares of analogue, DTT and cable (Figure 9). This scenario illustrates the importance of competition in the industry for the take-up of digital television and the success of analogue switchover.

[25] Indeed, the UK pay satellite operator BSkyB has officially announced in June 2004 its intention of doing exactly so. According to the press, this move is a strategic response to the competitive pressure from Freeview.

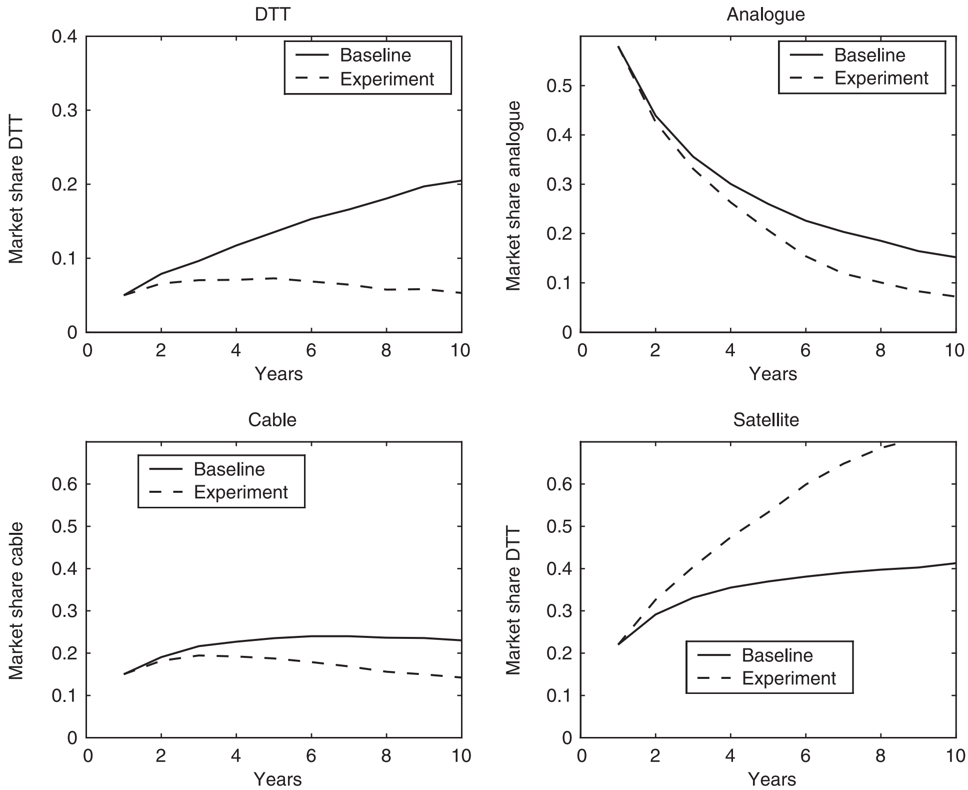

Figure 9. Effect of launch of free 'basic' satellite (Scenario 7)

5.2. Welfare effects

A benevolent government should switch to the digital standard provided that the social benefits outweigh the social costs of switching. Our model provides estimates of the impact of policies on consumer surplus, which can be directly used in cost-benefit analyses.

Table 6 reports the change in aggregate consumer surplus for each of our experiments. The sign of the impact of each policy is as expected. The increase in surplus is modest for most scenarios (less than 2% of the overall consumer surplus from television).

Early switch-off (scenario 6) leads to a reduction in welfare. This is due to the fact that this reduces consumer choice and requires a sizeable fraction of 'traditionalists' to convert to digital, even though they would have preferred to continue receiving the analogue signal. This leads to a reduction in consumer surplus of about 11.58%, corresponding to approximately £2.02 billion.

Table 7 reports the impact on consumer welfare of (expected) switch off at different periods. This consumer surplus cost from early switch off should be traded off with the other costs and benefits of switch off, such as (1) the benefits from the social value of the released spectrum, (2) the savings in duplication of transmission network, and

Table 7. Consumer surplus loss from switch off at different dates relative to baseline

Switch-off period	Impact on consumer surplus (£ billions)
3	−4.35
4	−3.86
5	−3.48
6	−3.12
7	−2.82
8	−2.64
9	−2.36
10	−2.02
11	−1.79
12	−1.57
13	−1.37
14	−1.18
15	−1.01
16	−0.83
17	−0.67
18	−0.52
19	−0.38

Notes: Each row corresponds to a scenario in which switch off is correctly expected to take place in the corresponding period. The second column gives the loss in consumer surplus compared to the baseline scenario of no switch off.

(3) consumers' costs (in terms of equipment and inconvenience) for converting the secondary television sets.[26]

The offer by the satellite operator of a free basic package (scenario 7) results in a very large increase in consumer surplus equal to £2.05 billion. This illustrates that market responses to policies can be very important also in terms of consumer surplus.

6. CONCLUSION

In this paper we have framed the current policy challenges for the transition to digital television. We have then built an empirical model of dynamic adoption by forward-looking viewers with heterogeneous preferences for television platforms offered at given prices. Our main methodological contribution is the formulation of a dynamic programming model of adoption in which agents have probabilistic expectations that the choice set changes over time due to analogue switch off. We have shown how to implement numerically the model to simulate the effect of a number of policies aimed at speeding up digital take up.

In order to illustrate the working of the model, we have calibrated it with estimates obtained from stated preferences data from UK viewers. Our calibration exercise has revealed that viewers have non-negligible switching costs. Among the viewers who

[26] The social value of the released spectrum is clearly different from its market value, due to the producer and consumer surplus created from the alternative use of the spectrum.

have not yet adopted a digital platform, there is a considerable number of 'traditionalists' who voluntarily migrate to digital only if analogue is not available.

A major advantage of our modelling approach based on adoption decisions made at the individual level is that we can ask how these decisions depend on the characteristics of the different household segments. Policies can then be designed to target exactly the population segments that would otherwise be least likely to adopt, the so-called 'refuseniks'.

We have then simulated the effect of these different policies on digital take up by comparing the simulations obtained for different parameter values. We have found that the availability of channels and content is an important driver of television adoption. In contrast, at current levels the cost of digital reception equipment is not a major determinant of viewers' adoption. Reduction in the cost of the digital reception equipment alone will not be enough for switchover.

Expectations of a switch-off date have important effects on digital take up. This is because there are almost no 'troglodytes', who prefer analogue to no television and no television to digital television. A firm commitment to early switch off is the most effective way to shift viewers from analogue to digital. Credible announcements are effective in achieving co-ordination, but the universality objective casts doubts on the credibility of such announcements.

If a firm commitment to a switch-off date is not politically feasible, policy makers can attempt to speed up digital adoption with a number of alternative policies. For example, governments could increase DTT coverage and programme quality or subsidize digital equipment. Our simulations show that these policies tend to bias the outcomes in favour of the DTT platform. This might explain why the competing platform operators might not favour these policies. All the policies we considered, other than the firm commitment to early switch off, have a limited impact on the fraction of analogue households.

The model does not allow for endogenous responses of the other platforms to these policies. In practice, it is natural to expect that the television platform operators will reduce the price and/or improve the content of their offerings in response to government policies. We have verified in our model that these competitive responses can be very important for overall digital penetration and consumer surplus.

We have conducted our exercise under the assumption that there is no disruptive innovation in broadcasting. There are many new technologies, now still in their infancy, that might affect future developments of broadcast market (Cox, 2004). Broadband, Personal Video Recorders and Micro-billing Payment Systems will probably change the future of broadcasting in a very profound way. The spread of broadband could speed up the convergence of digital technologies, resulting in a single delivery system for multimedia and telecommunication services. Personal Video Recorders can allow viewers to eliminate adverts, questioning the viability of advertising financed commercial televisions. Micro-Billing Payment Systems enable viewers to pay only for what they want and to use their television as an electronic bookshop.

These technologies will change broadcasting fundamentally, raising some doubts about the future of terrestrial television.

Discussion

Gabrielle Demange
Delta/ENS and CEPR

It is a pleasure to comment on this paper, which is well written, and very instructive for non-specialists of broadcasting technologies and television markets.

The paper describes the organization of television markets and the broadcasting technologies, surveys the various policies that have been implemented or decided upon in various countries. The innovative part of the paper is in the last section, which presents a micro-founded model estimated on UK data survey of households' behaviour. The model is used to simulate various policies (subsidies, date of switch-off, coverage of DTT) on households' behaviour and adoption of digital equipment in the UK.

The main points I want to raise are:

1. Is the transition to digital terrestrial television mainly a 'political' or a 'social' problem? What is the rationale for the government intervention examined in the simulations?
2. Do the simulations answer the (numerous) questions that are raised by the digital revolution and suggested by the descriptive part of the paper?

The rationale for government intervention in the switch over to DTT

Apart from some of the traditional rationales for government intervention, the paper argues that governments should intervene on the basis of political and social goals: governments may want to provide universal access, and promote high quality free public channels. Note that any platform – terrestrial, cable or satellite – can be digital. Terrestrial platforms are not the only way to achieve these goals.

Another rationale for intervention could be related to the optimal design of the allocation between the three platforms. As made clear in Table 1, the current market shares of the three platforms vary widely across European countries. In particular, in some countries – the Netherlands, Belgium, Luxembourg and Germany – the share of the terrestrial platform has been reduced almost to zero. While for the three first countries the high population density may favour cable, this is not likely to be true for Germany. These differences raise the question of the optimal design as a function of the geography of a country. The question is not considered in the paper.

It seems that the issue really addressed by the paper is the following one. The government, traditionally involved in terrestrial television broadcasting, wants to keep its network but is reluctant to upset voters who will have to pay for a set-top box. In other words, is the government intervention contemplated in the paper biased towards terrestrial technology, perhaps for historical reasons? To sum up, it would be interesting to clarify the objective of the government.

The simulations

A main lesson to be drawn from the simulations is that subsidies to low-income families are not necessary if the aim of the governmental policy is to speed up the adoption of DTT. Indeed, scenario 6, which entails subsidies to poor households either for DTT only or for all platforms, have no impact (compared to the baseline scenario) on the speed of convergence and on the final market shares. In view of Figure 2, which plots the marginal utility for the number of channels according to households' characteristics, this may not be very surprising. The troglodytes (if any) seem to be the 'old single rich'.

The key factor explaining the speed of the switch-over and the final market shares seems to be the coverage of DTT. This raises again the question of the optimal coverage of DTT and optimal design of the market shares between the platforms.

I now come to my second point. The two first sections make very clear the numerous and complex aspects of the television markets. As a result, it is somewhat frustrating that the simulations focus on a quite specific aspect of the problem, namely the speed of the transition to DTT. Apart from this frustration, this raises the question of whether the model is robust to the specific assumptions. Recent technological progress has a large impact both on the respective shares of the platforms and on competition at different levels. Since the model neglects many of these aspects, the reader wonders how robust the results are, and whether the question investigated by the simulations is really the most important one.

Finally, an important feature may be missing in the analysis. Cable allows access to Internet, and to interactive television. Also DSL is starting to offer both Internet and television. Whereas the model is very rich in explaining individuals' behaviour, it may neglect some technological issues that could dramatically affect the future.

Emmanuelle Auriol
IDEI, University of Toulouse and CEPR

The authors study the transition process from analogue to digital television. The paper begins with an extremely useful description of actual market outcomes and government intervention in television markets. It turns next to the study of the diffusion process of digital television. The analysis is conducted with the help of a micro-founded model. The model is simulated to assess the impact of various government policies. The paper is clear and well written, and it addresses an interesting issue.

My main concern with the paper is linked to the theoretical analysis of the diffusion process that is used in the simulations. We know from previous studies that the outcome of a decentralized adoption process depends on adopters' attitude towards incompatibility. In most cases standardization occurs on the optimal standard without the help of public intervention. This implies that public intervention is not likely to improve welfare unless multiple stable equilibria exist so that the adoption process exhibits path dependency and lock-in. This generally appears when there are public safety concerns. In the case of television standards there is no public safety concern. So why should we consider public intervention in the first place? A global co-ordination problem exists in all industries characterized by network externalities. This does not mean that public intervention is necessary or desirable to achieve sensible standardization. The only justification is that in the absence of public intervention the switch to the superior standard would not occur – a view that is not supported by the present analysis. Technically this could be supported by the shape of the probability function of switching from one standard to the other (given by Equation A10 in the Appendix). It suggests aversion to incompatibility (the probability function of adopting standard j is the ratio of exponential functions). This is a case where standardization under *laissez-faire* might occur on the inferior standard. When multiple stable equilibria exist there is indeed a problem of path-dependency. Government should intervene to avoid lock-in on the inferior standard. However, the model simulations do not show any path dependency. This result suggests that government intervention is not likely to be particularly useful, a result confirmed by the simulations in the paper.

An interesting contribution of the paper is that the authors explicitly consider the government decision to switch off the analogue signal on the diffusion process. This decision is obviously a radical way to influence the standardization outcome and to avoid the lock-in on the inferior standard. They study how different policies might hasten the decentralized adoption of digital technology by users. Indeed a large fraction of users should have already adopted digital television before the switch off of the analogue signal becomes politically possible. None of the public policies simulated has a significant impact on the market share of DTT except the policy 'expectation of an early switch off'. In contrast the effect of a free basic satellite service has a strong negative impact on the diffusion of DTT (and a strong positive impact on the adoption of satellite).

In conclusion I think that contrary to the basic assumption of the paper where the objective of the government is to maximize welfare, or at least the number of information sources that viewers can access, in practice governments have always tried to control mass media, especially television. This is obviously true for authoritarian regimes but it is also true for democratically elected governments. For instance, in France television was publicly owned and censored until the mid-1980s. Election outcomes are highly influenced by the information delivered to voters. Controlling this information is strategic for those who are in power. With television and mass media one should not expect governments to facilitate access to more sources of information if this means more political opposition. Fortunately the authors have convincingly shown that government intervention is relatively ineffective in hastening the switch to DTT. This suggests to me that they should not be heavily involved in the process.

Panel discussion

Marco Ottaviani replied to Emmanuelle Auriol's scepticism about the motives of government that analogous problems arise whether the agent is the government or a private organization. Importantly, the problem arises for both a benevolent government and an authoritarian one. Although he considered it interesting to investigate the different reasons why spectrum is allocated by the government, he emphasized that this is taken as given in the paper. Giuseppe Bertola urged the authors to consider the Italian case where the spectrum had been privatized. Marco Ottaviani added that in the US the spectrum had been allocated to local TV stations for free. However, the question remained open why the government should decide on the use of the spectrum and why in the UK, for example, the BBC should be paid to use the spectrum whereas ITV had to pay. Instead, the paper focused on a government that decides about the switch to digital TV under the constraints of universality and a limited spectrum.

Pierre-Olivier Gourinchas questioned the model's assumption that the consumer gets the full benefit of digital TV technology if he switches to the new technology. Governments often cannot offer this to consumers. Hence, the optimal timing of the subsidies is more complicated since the quality of digital TV will improve as the time approaches at which analogue TV is abandoned.

Hans-Werner Sinn thought that the paper should mention that the big advantage of the digital technology is pay-per-view. This should increase efficiency compared with the current practice of financing TV production with advertisements. Marco Ottaviani replied that the model in the paper does not address this issue. However, he acknowledged that the choice of the platform matters in this respect: cable platforms allow full interaction between the consumer and programme provider whereas satellite platforms allow only one-way interaction.

Shaun Hargreaves Heap mentioned that the commitment problem of the government with respect to switching off the analogue TV signal could be solved by transferring the decision to an independent agency. John Fingleton added that advance selling of the spectrum could also serve as a commitment device.

APPENDIX: DETAILS ON ESTIMATION AND MODEL

Equipment cost

We now discuss our specification of the 'learning curve' in the production and marketing of digital terrestrial STBs. We posit that the cost of a unit depends on the total number of units produced in the past. The idea is that more efficient techniques are adopted as cumulative output increases, leading to a reduction in unit cost. In the case of consumer electronic equipment, it is reasonable that the benefits of learning manifest themselves in lower production cost and more effective marketing.[27]

The price of a STB, $C(Q_t)$, is assumed to depend on total *cumulative* production of set-top boxes, Q_t, which is equal to the DTT take up in period t. The learning curve model specifies that this price (average cost of producing the marginal unit) has constant elasticity with respect to cumulative output:

$$C(Q_t) = a(Q_t)^b \tag{A1}$$

Since higher cumulative output results in reduction of cost, the value of b is negative. Taking logarithms on both sides of Equation (A1), we obtain the equation used to estimate the parameters a and b from the data:

$$\ln C_t = \ln a + b \ln Q_t \tag{A2}$$

According to this equation, average cost decreases by $-b\%$ for every 1% increase in cumulative output.

The 'slope' of the learning curve is defined to be equal to the ratio of the average cost of production of one unit as cumulative output doubles. By using Equation (A1), this is equal to:

$$s = C(2Q)/C(Q) = 2^b \tag{A3}$$

A slope equal to s means that the cost of producing one unit goes down by $(1 - s)\%$ as cumulative output doubles. This leads to the definition of the 'learning rate', $r = 1 - s$, which is equal to:

$$r = 1 - 2^b \tag{A4}$$

Consumer behaviour

This is a discrete time infinite horizon model. Periods are indexed by t and represent one year, starting with $t = 1$.

Consider the problem of an individual viewer h, belonging to one of the 12 segments of which our population is composed. Such a viewer has static preferences for television given by Equation (1), with estimated parameters, $\hat{\alpha}^h$ and $\hat{\gamma}^h$. In the following, we consider the problem of each individual viewer h, but drop the superscript for convenience. It is understood that the same value function is associated to all the viewers who belong to the same segment.

In order to set up the individual decision problem, focus on a particular viewer h at a particular period t. The platform/package combination that was chosen in

[27] The learning curve model originated in engineering studies of aircraft production, but has also been applied to other industries, such as chemical processing, energy and semiconductors. See Chapter 2 of Besanko *et al.* (2000) for an accessible introduction to the learning curve and additional references.

period $t-1$ by the viewer is denoted by $i = 0, 1 \ldots I$, where $i = 0$ denotes the choice of no television which is always available, $i = 1$ denotes the choice of FTA analogue terrestrial television, $i = 2$ is DTT FTA, $i = 3$ is cable FTA, $i = 4$ is cable basic and so on. The new choice of platform/package for period t is denoted by j.

Consistently with the model used to estimate the preferences, the instantaneous utility function of the viewer is specified to be:

$$\hat{u}(i, j, p_t, X_t, Q_t) = \hat{\alpha} X_t^j - \hat{\gamma} p_t^j - \hat{\gamma} c_t(i, j, Q_t) + \eta_t^j \tag{A5}$$

where X_t^j is a vector of characteristics of corresponding to package/platform j available in period t; p_t^j is the price of package/platform j at time t; $c_t(i, j, Q_t)$ is the cost of switching platform among those available in period t; and η_t^j is a shock to preferences.

According to this random utility specification, the shocks η_t^j are assumed to follow an extreme value distribution with mean zero and variance 1, following McFadden (2001), and are i.i.d. for all periods t and package/platforms j. These shocks capture idiosyncratic variations in preferences, accounting for the possibility that individuals with the same estimated preferences make different choices.

The switching cost $c_t(i, j, Q_t)$ is zero if the viewer keeps the same platform from one period to the next (i.e., when $j = i$), but positive otherwise (Klemperer, 1995). This cost has two components. First, there is a 'psychological' cost of changing platform, due to the inconvenience and time needed. Second, there is a 'physical' cost related to the fixed cost of the new equipment (set-top box, satellite dish, aerial or rewiring) needed to connect with platform j. The cost of switching to the DTT platform $i = 2$ from any other platform includes the price of a DTT STB, which is assumed to depend on overall terrestrial adoption Q_t (a proxy for the number of the total number of DTT STBs produced in the past), according to Equation (A1).

In any period t, the viewer chooses the platform from the set of available platform in that period I_t that maximizes her utility:

$$V_t(i) = \max_{j \in I_t} V_t(i, j) \tag{A6}$$

where $V_t(i)$ is the value associated with platform i, and $V_t(i, j)$ is defined recursively as:

$$V_t(i, j) = \hat{u}(i, j, p_t, X_t, Q_t) + \beta V_{t+1}(j) \tag{A7}$$

All viewers are assumed to believe that switch off will take place in a certain period $t = S$. This means that the set of available platforms is believed to shrink in period $t = S$ from the set of all platforms *including* the analogue terrestrial platform $I^A = I^S \cup 1$, to the set I^S. There are two phases, depending on whether switch off has already occurred ($t \geq S$) or not ($t < S$).

'Post-switch' phase (S)

The choice set then is equal to $I_t = I^S$, for all periods $t \geq S$ after analogue switch off. We assume that the environment is stationary in the post-switch phase, with no changes in prices $p_t = p^S$ and package/platform characteristics $X_t = X^S$. The (endogenous) price of DTT STB is also constant in this phase, since $Q_t = Q^S$.[28]

In this stationary phase, the value function for each segment is then constant (i.e., not time dependent) and equal to the fixed point of Equations (A6) and (A7), denoted by:

$$V_t(i) = V^S(i) \tag{A8}$$

'Pre-switch' phase (*A*)

The choice set is equal to $I_t = I^A = I^S \cup 1$, for all periods $t < S$ before analogue switch off. The problem in this phase is non-stationary, so there is a different value function for each period. These value functions are:

$$V_t(i) = V_t^A(i) \tag{A9}$$

These value functions are found by backward induction using Equations (A6) and (A7), using the post-switch value given by Equation (A8) as the terminal condition.

Identification

We now explain our strategy for estimating the preferences of the consumers to be used in our simulation model. This is usually done with panel data recording individual adoption choices made over time. Such data are not available in our case, as it is typical for new products. Instead, we use different data sources.

We separate the parameters of the model into two categories, those pertaining to the per-period utility function (α and γ), and those pertaining to the inter-temporal choice (discount factor and switching costs). We use survey data to identify the first set of parameters and aggregate data on adoption of platforms to identify the second set of parameters.

Viewers' preferences

We estimate these preferences from individual-level data of stated hypothetical choices. In our survey, the same individual is asked to make many different decisions at the same time. There are two advantages with respect to revealed preferences data. First, there are no changes in the environment when different decisions are made. Second, there is a large amount of systematic variation in prices and characteristics.

The surveyed individuals were asked to make a number of decisions between two options, each consisting of a television package with different characteristics and

[28] More precisely, we are focusing on an equilibrium in which the share of DTT is constant, and so the DTT STBs do not vary in the post-switch phase.

delivery platform, and offered at different subscription prices and fixed set-up cost. In addition, individuals were also asked to report their socio-economic characteristics.

We use the variation in this data to estimate how viewers trade off the characteristics of packages (represented by the vector X) and platform with a per-period subscription price (vector p), according to Equation (1).

The choice of a platform depends not only on the quality/subscription price tradeoff, but also on the initial installation cost and on how long the choice is made for. In particular, the importance of the installation cost relative to the subscription price is difficult to establish. This is because surveyed individuals rank platforms according to their preferences and their inter-temporal horizon, which can vary across individuals and about which we have no information.

For this reason, we do not use directly the information on the installation cost in the survey. However, the installation cost is correlated with platform characteristics and subscription prices (better platforms such as cable or satellite are more expensive to install), so omitting it from the regression would bias the coefficients. To avoid omitted variable bias, we control for the installation cost in the regression. To abstract from differences in the planning horizon across individuals, we further include an individual fixed effect in the regression model. This is possible as we observe many choices per individual.

Preferences for no television

Unfortunately, our survey did not include the option of no television for the corresponding saving in licence fee. For the purpose of forecasting how many viewers would opt out of television in scenario 5, we need to estimate the utility of no television. We have set this to the value that guarantees that in the baseline version of the model the fraction of viewers without television matches the corresponding empirical frequency in the UK population (equal to 1%).

Our results are in line with those we have obtained from data from another survey containing direct information about the preferences for no television.

Switching costs

In order to calibrate the 'psychological' part of the switching cost, we have used the initial evolution of the market shares of the different platforms. This cost is set at the level that minimizes the quadratic distance between the predicted and the observed market shares in the first two years. This led us to an estimate of £200 for the 'psychological' switching cost.

Solution

The model is solved by backward recursions, starting from the post-switch phase. We start with an arbitrary guess for the value function and iterate Equations (A6) and (A7) until we converge to the stationary solution. We then solve for the optimal pre-switch value functions using Equation (A8) and (A9).[29]

Given our assumption that the taste shocks are independently and identically distributed over time and follow an extreme value distribution, the probability of switching from platform i to platform j is given by this simple formula, which generalizes the logistic model to our dynamic setting:

$$\Pr_t^h(i \mid j) = \frac{e^{V_t^h(i,j)-\eta_t^{h,j}}}{\sum_l e^{V_t^h(i,l)-\eta_t^{h,l}}} \tag{A10}$$

The model gives us the value of each package/platform in each period for each segment of the population, along with the switching probabilities, for any given vector of prices and characteristics and expected switch-off date. To obtain the aggregate adoption path for each platform, we then aggregate over the 12 consumer segments and over the packages based on the corresponding platform.

The model is solved conditional on a guess for the path of prices for DTT STBs. However, these prices are endogenous to the model, being determined by the take-up of DTT. In equilibrium, the price path should be consistent with the actual uptake of DTT it generates.

Numerically, we proceed by first guessing DTT STBs prices for all periods. We then solve the model and obtain the predicted DTT uptake and hence the cost of production according to Equation (A1). Finally, we use this new series of prices to generate new demands, until prices and demand are consistent.

Welfare

Given our quasi-linear specification of preferences, our model can be used to compute the effect of different policies on consumer surplus. This is because the first-period value function V_1^h of each viewer belonging to segment h gives a direct measure of welfare. This can be translated into monetary terms (in £ at period 1) by dividing through by the corresponding marginal utility for money γ^h.

The representative consumer surplus is then obtained by weighing the different segments according to their share of the population. The aggregate consumer surplus is then obtained by multiplying the representative consumer surplus by the number of television households in the UK (25 million). The estimated value of total consumer surplus in the television market in the baseline scenario of our model is equal to £17.42 billion.

[29] We refer the reader to Adda and Cooper (2003) for a general exposition on how to solve dynamic discrete choice models by value function iteration and to Adda and Cooper (2000) for an application to policy evaluation.

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