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PUBLIC SUPPORT FOR THE FINANCING OF RD&D ACTIVITIES IN NEW CLEAN ENERGY TECHNOLOGIES

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Abstract

Several market failures, as well as other technical, economic and regulatory barriers to the market penetration of clean energy technologies result in under-investment of private innovators in RD&D. Therefore, public support is needed in order to induce innovations. Policy tools creating market conditions that are attractive for the exploitation of clean technologies (market pull) must be combined with other tools directly supporting the development of these technologies through the provision of public funds (technology push). Thereby, financing policy instruments should be chosen so that their characteristics match with those of the specific innovation process being targeted at the same time that social welfare is maximized. We develop an analytical framework to define the form of public support and to provide recommendations on the optimal choice of both technology push and market pull instruments.

Keywords

Clean energy technologies, innovation finance, public support, technology push, market pull.

1 Introduction[1]

In order to stabilize the concentration of greenhouse gases in the atmosphere and to reach the EU climate objectives, a portfolio of low-carbon energy technologies has to be employed at a large scale and investments enhancing energy efficiency have to be undertaken. This requires substantial activities in research, development and demonstration (RD&D) targeting the development of new technologies as well as achieving capacity cost reductions for existing clean technologies in order to make them competitive compared to traditional fossil fuel based options (see also EC, 2009).

Market failures, as well as other technical, economic and regulatory barriers to the market penetration of clean technologies result in under-investment of private innovators in RD&D. In the absence of any public support, this is likely to lead to a situation where the level and timing of investments are suboptimal from a social point of view. Traditionally, technology innovation experts have discussed the choice between Technology Push (TP) instruments directly supporting the development of new technologies through the provision of public funds, and Market Pull (MP) instruments aimed at creating conditions in the market that are attractive for the exploitation of clean technologies by private parties. As industry experts already have argued (see e.g. Foxon, 2003), TP and MP instruments are complementary means and should be combined depending on the features of each technology. This article shows that:

1 // Market Pull instruments are needed to improve and drive down the cost of clean technologies that are already available but are not mature enough, as well as to encourage their use (see also Grubb, 2004);

2 // Public funds must be provided, too, if clean energy innovation projects that are socially valuable but not commercially attractive are to be undertaken;

3 // Specific instruments, or policy tools, to support each technology must be chosen so that the characteristics of these tools match those of the specific innovation process being targeted.

After discussing the need to apply both Market Pull and Technology Push instruments, we aim to guide the choice of the specific policy tools of both types to implement according to the type of clean energy innovation to support. When designing the policy supporting the development of clean technologies, authorities must aim to maximize the social benefits produced by these technologies. This must be the overarching principle guiding public policy action and will be repeatedly referred to throughout the article.

The rationale for the provision of public support to clean energy innovation is provided in Section 2. Section 3 presents the overall framework used to choose the form of this support (policy tools to apply). The application of Market Pull instruments is discussed in Section 4. That of Technology Push instruments is discussed in Sections 5 and 6 with Section 5 focusing on the determination of the public financing needs of each innovation process according to its type and Section 6 on the selection of TP instruments to apply to support this innovation process, i.e. in order to cover the financing needs at lowest cost. Finally, Section 7 concludes.

[1] This work has been funded by the European Commission FP7 project THINK and has been led by David Newbery (EPRG, University of Cambridge). The authors thank the chairman of the THINK expert hearing Ronnie Belmans, the invited experts Reinhilde Veugelers, Michael Grubb, Pantelis Capros, and Christian von Hirschhausen, as well as the industry representatives for their useful comments on an earlier draft of this paper. The analysis and conclusions are the sole responsibility of the authors.

2 Rationale for public support

The level of public involvement in the development of new technologies should be kept as low as possible since the private sector is believed to be best suited to manage risks and to identify those investment options with the highest potential. However, there is ample evidence that achieving an optimal development of clean energy technologies requires some public support.

Existing market failures prevent clean energy innovators to capture the marginal benefits produced by the availability of clean technologies. First, the absence of a credible and appropriate carbon price (see e.g. Aghion et al., 2009) results in the inability to correct the positive externality resulting from clean technologies mitigating CO_2 emissions. If clean energy innovators' revenues are not in accordance with the marginal environmental benefits brought about by the development of clean technologies (i.e. *social spillover*), their investments in clean energy RD&D are sub-optimal. Second, the ability of market agents to profit from an innovation by a competitor creates a *spillover* of the benefits of the corresponding technology *over the market*, thus again leading to weak private incentives for clean energy innovation investments. This may be corrected by arranging regulating the access to this technology by market agents. Third, some clean technologies may benefit others that need the former to operate. The availability of these clean technologies creates a *network spillover* of their benefits that innovators should be compensated for in order not to weaken their investment incentives. Market failures of these three types, which lead to social, market and network spillovers, may be corrected through the use of policy instruments[2].

Overcoming certain technical barriers to the penetration of the market by clean energy technologies requires achieving the massive production and use of these technologies (the so called learning by doing). In order to reach EU climate policy goals, a further development and deployment of low-carbon technologies is necessary. However, market agents shall not massively install and use new clean technologies that are still not cost competitive unless their use is publicly supported. Policy instruments aimed at correcting spillovers and supporting the demand for new technologies (i.e. Market Pull (MP) instruments) should help trigger private innovation while not involving the direct provision of public funds.

Contrary to what happens in other fields such as pharmacy, MP instruments may be unable or unsuitable to completely correct existing market failures affecting clean energy technologies[3]. Additionally, there are further barriers to the development of clean energy technologies that are not (completely) addressed by MP instruments[4]. Thus, for example, innovations in clean energy technologies often pair very high capital requirements with substantial technical, economic and regulatory uncertainties hampering the involvement of the private sector. Besides other relevant barriers, economies of scale favor a lock-in impeding the market entry of new technologies[5].

As a consequence, a gap between the cost of financing the development of a clean energy technology and the funds that private parties are willing to contribute is likely to remain once MP instruments have been put in place. The size of this financing gap depends on the cash flow of the concerned innovation process and can be determined by carrying out the same cost-benefit analysis conducted by innovators whereby they decide whether to undertake this process. Public funds must be

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[2] Different market failures to (low-carbon) innovation are also discussed in Martin and Scott (2000) and Foxon (2003). For an overview on theoretical analysis of the effects of environmental policy on technological change see Jaffe et al. (2002).

[3] See the discussion on the management of intellectual property in Section 4.

[4] A comprehensive discussion of the barriers to innovation in clean energy technologies is provided in Neuhoff (2007).

[5] For a detailed discussion on the funding gap in the financing of R&D and innovation originating in imperfections of financial markets see Hall and Lerner (2009).

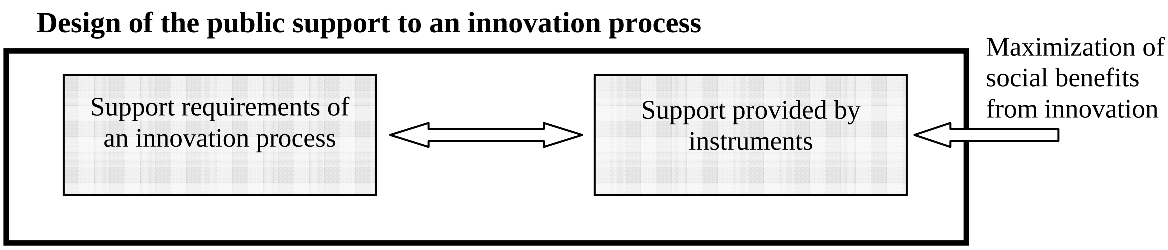
directly mobilized to cover the financing gap of clean energy innovation processes that MP instruments are unable to cover. This involves the application of Technology Push (TP) instruments.

3 General analytical framework

In order to be effective, the type and amount of public support to be provided to an innovation process must be conditioned by the characteristics of the concerned technology and its stage of development. Additionally, authorities must aim to maximize the overall increase in social welfare resulting from the support of this and other clean innovation processes.

We propose a methodology to be used to choose financing policy instruments in order to support RD&D investments in clean energy innovations. This methodology can be deemed to be divided into three steps. First, one must characterize the concerned innovation process in terms of variables that are related to the type of technology to be developed and its maturity. Second, the type of public support that this process requires must be defined based on the characteristics of the latter. Finally, taking into account the type of support needed by this process and the objective to maximize the overall social benefit of clean energy innovation, the characteristics of the support instruments to use must be determined and the specific instruments that best match these characteristics must be identified. The identification of the instruments to be used to support a generic innovation process is illustrated in Figure 1.

Figure 1: General analytical framework



4 Market pull instruments

Each of the three steps to be taken to select MP instruments that should support an innovation process is addressed in a separate subsection.

4.1 Main features of an innovation process relevant to the choice of MP instruments to apply

The main features of an innovation process to be considered when determining the type of indirect support it needs (i.e. MP instruments to be applied) are related to the characteristics of the concerned technology and its level of maturity. These features include the following:

» *Stage of development of the technology:* The level of maturity of a technology conditions the timing of revenues and expenses resulting from its development. Additionally, the level of maturity of this technology relative to that of alternative clean technologies potentially competing with the former may significantly condition the type of support to be provided. Support to be received by mature technologies may promote competition among them while support to immature technologies must be more specific.

» *Interdependence between this technology and other new technologies:* The fact that the concerned technology is dependent on other new energy technologies, or other new technologies are dependent on the former, shall condition the potential level of deployment of one and the others. This will in turn condition the level and type of support needed by an innovation process.

» *Type of knowledge acquired through innovation:* meaning whether this innovation represents an incremental knowledge advance or a breakthrough.

» *Structure of the demand for this technology:* The relative weight of the private and public sectors as potential consumers of the concerned technology conditions the potential of the public sector to drive the development of the market for this technology.

4.2 Identification of the type of indirect support needed by an innovation process

MP instruments are used to provide indirect support to an innovation process through the creation of market conditions that are more advantageous for the innovator. One cannot neglect the fact that market conditions where the exploitation of a technology shall take place affect the commercial viability of this technology and therefore have a direct impact on the needs for direct public support. A distinction is made between indirect support provided to correct existing spillovers and the support to the development of the market for the considered technology.

4.2.1 Support needed for the correction of spillovers

The type of support needed to deal with the spillover of the benefits of innovation depends on the type of existing spillovers and whether correcting these spillovers, or compensating the innovator for them, is possible and desirable. The capability of authorities to correct a spillover and the advisability to do so depend, in turn, on the type of spillover considered. Thus, the support to be provided for the correction of spillovers is discussed separately for each type of spillover.

» *Social spillover*: Clean energy technologies involve a reduction in CO_2 emissions and therefore give raise to social spillovers. This environmental externality should be addressed through the implementation of a carbon pricing scheme. The correction of this externality is always desirable. Applying a price to CO_2 emissions plays a central role in achieving the objectives of climate policies by increasing the commercial appeal of these technologies.

» *Network spillover*: This spillover exists when other new technologies are dependent on the considered one or the market value of the former increases due to the availability of the latter. Network spillovers can and should always be corrected through the regulation of the revenues earned by those entities exploiting the corresponding technology. This will encourage the use of new technologies developed.

» *Market spillover*: Market spillovers are present for most technologies, since part of the knowledge produced by the development of a new technology can be appropriated by competitors though backward engineering. It can be corrected more easily the more different this technology is from others existing in the market, since detecting a breach of property rights is easier when the technology that is being copied can be clearly distinguished from any other. Thus, protecting radical innovations from market spillovers tends to be possible, while protecting incremental innovations is much more difficult. Tightening intellectual property rights, which could be claimed by those private parties contributing funds to innovation, could nevertheless endanger the spread of clean technologies.

4.2.2 Support needed to increase the demand of the concerned technology

This support is aimed at facilitating the massive production and use of a clean technology in order to gain the knowledge required to overcome existing technical barriers as well as to accelerate the replacement of damaging fossil fuel technologies. Now, we discuss those features of a clean technology that determine the type of support this technology requires to increase its installed capacity and use. We also show how features discussed here depend, in turn, on those previously identified in Section 4.1:

» *Ability of the public sector to pull the demand for the considered technology:* This depends on the structure of the potential demand for this technology (relative weight of the public and private sectors as consumers). If the public sector is a potential large consumer of this technology, policies to increase the demand for this technology could focus on this sector.

» *Capacity of this technology to compete with others*: This depends on the level of maturity of the concerned technology. If the concerned technology is less mature than other new clean technologies, the demand for all these technologies cannot be jointly supported because technology consumers would make use of the more mature ones.

» *Likelihood that the support for this technology must be cut off*: This depends on the stage of innovation addressed or level of maturity of the concerned technology. The less mature a technology is, the more probable it is that technologies finally chosen to be massively deployed are others rather than the former. If support for a technology may likely need to be cut off in the future, this support should not be committed for a long time or lead to a situation where authorities are locked into funding this technology.

» *Reliability of the considered technology*: This depends on the level of maturity of the technology. More mature technologies tend to be more reliable. The reliability of a technology should condition whether to support its installation or use. The development of an already reliable technology can generally not be accelerated by increasing the use of this technology. Then, public support to this technology should reward its installation, thus avoiding the interference of public support with market prices. As for unreliable technologies, rewarding their use would encourage innovators to overcome the reliability barriers it faces while, at the same time, increasing uncertainty about the level of support they will receive[6]. Support provided by schemes rewarding the installation of unreliable technologies would be predictable but would not encourage the innovator to overcome existing reliability barriers. Then, unreliable technologies could be supported both rewarding their use and their installation.

4.3 Selection of Market Pull instruments

Here, we discuss the situations where different MP instruments should be used. MP instruments aimed at correcting spillovers are discussed separately from those supporting the demand for the concerned technology.

4.3.1 Selection of instruments correcting spillovers

Criteria to be used for the assessment of the application of instruments

Policy instruments should be applied to avoid, or compensate technology innovators or users for, those existing spillovers that can and should be corrected. Within the range of policy options that are able to correct these spillovers, authorities should choose the instrument to apply based on the impact of each of these instruments on social welfare. Arguments on the impact on welfare of different policy instruments are beyond the scope of this article. Welfare maximizing arguments relevant for environmental externalities can be found in Cropper and Oates (1992) or Grubb et al. (2007). Arguments on the use of policy tools to correct market spillovers (mainly patents) are provided in Jaumotte and Pain (2005). Joode et al. (2007) discuss several implications of the use of policy instruments to correct network spillovers.

[6] Under a support scheme rewarding the use of an unreliable technology, the amount of public funds to be received would depend on the innovators' ability to overcome existing reliability barriers.

Assessment of the use of specific available instruments

Instruments aimed at addressing different types of spillovers are discussed separately:

» *Social spillovers:* Financing policy instruments targeted at correcting social spillovers (in the case of clean energy technologies, environmental externalities) include the establishment of a carbon price, via the use of a carbon tax or a cap-and-trade mechanism, or the use of a white certificate scheme. Carbon prices are aimed at supporting both clean generation and energy efficient technologies while white certificates are specifically aimed to support energy efficient technologies.

» *Market spillovers:* Policy instruments targeted at correcting market spillovers mainly involve the implementation of enforceable property rights over the production and use of new technologies or over the knowledge needed to produce and use them (patents). These instruments should only be applied when correcting existing market spillovers is possible and desirable. As explained in Section 4.2.1, patents can only avoid market spillovers when the knowledge they refer to can be clearly distinguished from that produced elsewhere. In other words, they would be most effective to protect radical innovation or knowledge produced in the first stages of the innovation chain (basic research). There is a trade-off between providing incentives to invest in innovation via intellectual property (IP) protection and achieving a faster spread of clean energy technologies, especially in developing countries, via open access to knowledge. Exclusive rights to knowledge produced in innovation should not block the spread of this innovation. However, the use of these rights, though limited, may probably be needed to trigger the participation of the private sector in clean RD&D, especially in the case of small innovators.

» *Network spillovers*: Instruments addressing network spillovers of a technology must compensate users of this technology for the benefits that it renders to the users of other technologies. Thus, a regulated remuneration scheme is adopted for companies using technologies that produce network spillovers. Rate of return remuneration schemes, which guarantee a reasonable rate of return on investments, are applied to compensate for the use of not cost competitive technologies. Incentive-based remuneration schemes (price cap, revenue cap) set extra incentives for companies to reduce expenditures. Therefore, they are well adapted to reward the use of mature, cost competitive, technologies.

4.3.2 Selection of instruments supporting the demand for a new technology

Criteria to be used for the assessment of the application of instruments

Whenever the public sector is a potential large consumer of a technology, support policies should only affect it, thus avoiding the interference of this support with the functioning of the rest of the market.

Besides, clean technologies that are mature enough to be deployed but not cost competitive compared to alternative clean options should be supported separately from the latter. On the other hand, the demand for all those clean technologies that are mature enough to compete with alternative clean options should be jointly supported. This would create a competitive pressure that should drive down their cost.

The demand for technologies that are unlikely to be winners, and therefore to be massively deployed, should be supported through instruments that do not create long term support commitments and do not lead to authorities being locked into this support. On the other hand, the demand for clean technologies that most probably will be massively deployed (though they still have to go some way down the cost curve) should be supported through instruments providing more stable investment signals even when they also create long term support commitments.

Finally, when choosing which instruments to apply, authorities should also consider the suitability of each of them to back a technology based on the level of reliability of the latter. Aspects to be taken into account in this regard include the incentives provided by each instrument to overcome reliability barriers, the level of certainty provided by this instrument over the amount of support provided and the level of interference of the instrument with the functioning of the market (prices).

Assessment of the use of specific available instruments

Main types of instruments aimed at supporting the demand for a technology include those that support the investment in capacity of this new technology; those that support the current use of this technology and those that directly enforce the use of this new technology. The application of each of these types of instruments is assessed next according to the criteria already identified.

(a) Instruments financially supporting the current installation of capacity of a new technology

These instruments typically involve the application of capacity payments to generation companies, transmission and distribution system operators. These instruments do not create long term commitments to support the installation of capacity not yet built (the level and target of support payments can be regularly updated). However, payments affecting already installed capacity cannot be abolished or changed. The level of flexibility of these instruments can be deemed relatively high.

Capacity payments are both able to target specific technical options or promote competition among technologies, since their level can be separately set for each technology or a common level can be applied. These payments are aimed to encourage the use of the corresponding technology in the private sector. Applying capacity payments to support the use of this technology in the public sector would amount to creating a cross subsidy between different units or departments of the public administration. Then, these instruments should not support the demand for technologies mainly used in the public sector.

Finally, these instruments do not interfere with all the functioning of the market, i.e. they do not alter directly market prices (see also Newbery, 2010). Thus, capacity payments are well suited to support the deployment of reliable technologies, whose output does not need to be rewarded. They may also be used to support the deployment of unreliable ones because capacity payments provide stable investment incentives even when they do not encourage innovators to overcome reliability barriers.

To sum up, arguments exist to apply capacity payments to support the demand for both mature technologies that can compete with clean alternatives, or are even winning technologies, and immature technologies.

(b) Instruments financially supporting the current use (output) of a new technology

These instruments can be classified according to the stage of the electricity value chain where this technology is employed:

» *Electricity generation technologies*: here, a distinction is made between price-based and production-quota-based instruments. Price-based instruments (feed-in-tariffs, market premiums) provide a long term commitment to support the use of already existing capacity but not the use of that capacity yet to be installed. They are able to target each technology separately or jointly support several technologies and are not well suited to support the use of a technology in the public sector. Therefore, in this regard they exhibit the same characteristics as capacity payments. However, unlike capacity payments, they encourage innovators to overcome the existing reliability barriers of the concerned technology at the expense of interfering with market prices. Then, these instruments might be used, either to support the demand for not yet reliable clean generation technologies, or to accelerate the deployment of already mature technologies. If technologies supported can compete among themselves, the level of support payments should be common to all of them. Finally, the demand for the technologies supported should not mainly come from the public sector.

Production quota based instruments (e.g. a minimum share of renewables in electricity production) are aimed at creating competition among different clean technologies. Thus, the targeting of a specific technology is typically not possible. If these instruments are meant to influence the investment behavior or companies, they should provide stable signals and therefore a long term commitment. However, quota instruments provide flexibility regarding the technologies to be used to comply with this commitment (which, as already mentioned, affects several clean technologies competing among themselves). These instruments can be designed to only affect the demand for a certain group of technologies in the public sector. They might be used to encourage innovators to overcome reliability problems but interfere with market prices. Production quota based instruments are, in principle, best suited to support clean generation technologies that are mature enough to compete against other clean options and whose demand may or may not mainly come from the public sector.

» *Network technologies:* The remuneration scheme applied to reward the installation or use of transmission and distribution clean technologies can support the development of demand for these technologies. As already mentioned above, rate-of-return regulation is best suited to support the demand for reliable but not cost competitive technologies (though they could also support the demand for unreliable ones) while incentive-based regulation is best suited to support the demand for cost competitive technologies[7]. Rate of return remuneration schemes involve the assessment of each specific investment proposal made by the network operator. Therefore, they can be used to target a specific technology. Rate of return schemes do not need to commit long term support to any technology, but investments already incurred must be remunerated. On the other hand, incentive-based schemes are output driven. Therefore, they cannot target any specific technology. Both types of schemes may be applied only to specific companies. Therefore, they can be designed to affect the demand for a technology or technologies only in the public sector.

To summarize, rate of return remuneration schemes are best suited to support network technologies that are not cost competitive yet compared to alternative clean options while incentive based schemes are best used to support the demand for cost efficient technologies. Under both types of schemes, the technology or technologies supported may or may not be mainly consumed by the public sector.

(c) Instruments directly enforcing the use of a new technology

Instruments to be considered here include standard setting; niche management and long term requirements and obligations.

Standards have a long lasting effect on the technologies available in the market, killing competitors not complying with the standard. Therefore, they can only be used to support clean technologies, or groups of technologies, that have proven to be superior to alternatives (winning technologies). As suggested, standards can refer to a specific technology or group of technologies and their application can be limited to a certain fraction of the potential demand for a new technology (the public sector). Thus, they are well suited to target winning clean technologies that may or may not be mainly consumed by the public sector.

Niches provide a reduced but relevant market for a specific technology option or group of technologies competing among themselves (e.g. via public procurement programs). Given that they target a reduced market segment, support commitments provided though niche management can be altered more easily than those provided by standards. Then, niches should be created to support clean technologies that have not yet proven to be winners (they may be cost competitive or not, or even not yet fully reliable) and have the public sector as a major consumer.

Finally, long term requirements and obligations determine in advance the features of technologies to be used in the future, or performance objectives to be met by these technologies (e.g. obligation to

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[7] A incentive-based remuneration scheme could set incentives directly related to the installation of capacity of new technologies (for example, incentives for network companies linked to the amount of RES generation they connect to their networks). In this case, this remuneration scheme could also be promoting the use of technologies that are not cost competitive.

refurbish old buildings using advanced insulation materials, micro-generation etc. before being able to resell them). They must be designed to provide a long-term inflexible support commitment that result in strong enough investment incentives. They can both be designed to target a specific technology or promote competition among several clean technologies. Finally, long term requirements can affect only the public sector or the whole potential demand for a new technology or technologies. Long term requirements are best suited to support technologies, or groups of technologies, that still require some time to become mature (they may not be reliable yet) but are deemed to be necessary in the future.

5 Characterization of an innovation process relevant for the use of Technology Push instruments

Public funds need to be mobilized to support clean energy innovation that is socially desirable but not commercially attractive even when MP instruments have been put in place. This section discusses the set of criteria that condition the type of *direct* financial support to be provided to an innovation process. These criteria are intimately linked to some basic features of innovation processes that are identified first.

5.1 Main features of an innovation process relevant to the choice of TP instruments

The characteristics and stage of development of a clean technology condition the type of direct financial support needed. Most of the features to be considered have already been discussed when analyzing the use of MP instruments and will therefore only be mentioned here. These are the stage of development of the technology, the dependence of this technology on other new technologies, and the type of knowledge acquired though innovation (i.e. radical vs. incremental innovation). Additionally, the level of costs incurred in the innovation process addressed is also relevant to define the type of direct support to be provided, since it conditions the amount of public funds to be provided in order to engage innovators in this process. The level of costs incurred in an innovation process depends both on the type of technology and the stage of innovation addressed.

5.2 Identification of the type of direct support needed by an innovation process

Based on the features of an innovation process just identified, we discuss the set of criteria that determine the type of direct financial support required by this innovation process:

» *Size of the financing gap:* In order for an innovation process to be carried out, the gap between the costs to be incurred in this process and the funds that private investors' are willing to contribute once the appropriate MP instruments have been put in place must be covered using public funds. The size of the gap to cover can be determined by conducting the same cost-benefit analysis that potential private investors carry out to decide whether to undertake the corresponding innovation process. This cost-benefit analysis shall take into account the level of costs incurred in the innovation process; the level of revenues expected to be earned by any single entity from the exploitation of this technology in the market; the probability that this technology fails to reach the market and the timing of market revenues[8].

» *Targeting of the concerned technology:* this is conditioned by the following two technology features:

- *Capacity of this technology to compete with others for public funds*: This depends on the level of maturity (stage of development) of the technology. If the concerned technology is less mature than

[8] It can be easily shown that all these variables are in turn dependent on the main features of an innovation process defined in Section 5.1.

alternative clean technologies that are also to be publicly funded, the decision on which technologies to receive public funds cannot be left in the hands of innovators. This is due to the fact that the private sector has a natural incentive to invest in those technologies that are closer to the market and, therefore, closer to rendering market revenues. Therefore, in this case, funds should be directly assigned by public authorities to the concerned technology. On the other hand, those clean technologies that are, at least, as mature as alternative clean options should be left to compete for public funds, since this competitive pressure could help drive down their costs.

- *Likelihood that the support for this technology must be cut off*: This depends on the stage of development of the technology to be supported as well as on whether the innovation activity to be carried out represents a knowledge breakthrough or an incremental increase in knowledge. The less likely a technology is to reach the market, the easier it should be to redirect public funds to supporting other technologies.

» *Type of innovating entity carrying out this process:* The ability of the direct support provided to trigger successful innovation depends on how likely it is that this support is efficiently used by the type of entity deemed to carry out this innovation. The level of costs incurred in an innovation, its strength (radical vs. incremental) and the level of dependence of the concerned technology on other new technologies jointly determine which type of entity is best suited to conducting the corresponding innovation process. Thus, high RD&D costs can only be afforded by big entities; hence, while radical innovation is best carried out by small innovating entities and incremental innovation is best adapted to big incumbents. An innovation involving several technologies is better carried out by entities with cross technology expertise or through collaborative research.

6 Selection of Technology Push instruments

Before being able to determine which policy instruments may be used to publicly fund an innovation process, we need to identify the features of these instruments that are relevant to determine whether each instrument is well suited to provide the kind of support needed by the considered process. Afterwards, we assess the application of the main existing TP instruments.

6.1 Criteria to be used for the assessment of the application of instruments

As discussed in Section 5.2, instruments to apply to publicly fund the development of a certain technology should be chosen taking into account the type of support needed by this technology and the overall economic objective of maximizing social benefits of all the innovation conducted. Reducing the public cost of direct support provided to an innovation process should leave room for a larger number of additional promising innovation processes (a larger amount of clean energy innovation) publicly supported and should lead to a more efficient use of overall innovation funds available. This, in turn, should increase the overall social welfare. Therefore, TP instruments applied should involve the lowest public cost possible that is compatible with this process being undertaken.

Based on all this, the three main criteria finally chosen to assess the application of TP instruments to an innovation process are (i) the ability of each instrument to fund this process at a reasonable cost; (ii) the targeting this instrument makes of the concerned technology and (iii) the type of innovator that is well suited to received support through this instrument. The ability of an instrument to fund a process at a reasonable cost is in turn related to the size of the funding gap that the former is able to cover and the public cost of applying this instrument. The targeting an instrument makes of a technology depends on its ability to fund a specific technical option and its flexibility in redirecting funds to alternative projects.

6.2 Assessment of the use of specific available instruments

There are three general types of technology push instruments: loans/loan guarantees, those whereby the public administration acquires an equity share of an innovating company (Public-Private-Equity-Partnerships, or PPEPs), and subsidies. Thereby, subsidies can be classified into three different types: prizes awarded to the winner of a contest to carry out a certain innovation, tax credits, or other benefits, granted in return for undertaking private investments in new technologies, and grants or contracts that are awarded ex-ante to an innovating entity or consortium and whose size may or may not be conditioned by performance.

Using the set of criteria defined in this section to assess the performance of the application of TP instruments, we now discuss which types of innovation processes may well be financed with each of these policy instruments. Table 1 provides the main conclusions drawn from our analysis.

6.2.1 Provision of public loans or publicly backed loans

(a) Ability of this instrument to fund innovation at a reasonable cost

» *Size of the financing gap it is able to cover*: Loans are less attractive to innovators than subsidies, since the amount of funds obtained must be paid back to the investor together with the agreed interest rate. Public loans are able to close the financing gap of innovation processes that are not subject to a significant level of risk and are expected to lead to revenues in the short-term. They can also be used to fund low-cost innovations that are far from the market, and therefore subject to significant risks, but might render high market revenues to the innovator, who should be able to appropriate part of the social benefits produced.

Private lenders should also probably be willing to finance this innovation, while they are better suited than public authorities to manage risks. However, public loans (or loan guarantees) may probably have to replace private ones when capital markets are not liquid enough or when, due to asymmetry of information, the public administration is better informed about the risks involved in the innovation process and, therefore, is prepared to offer more advantageous interest rates[9].

» *Public cost:* In those cases where the innovating entity is deemed to be able to pay back a loan with a high enough level of certainty, public loans (or loan guarantees) are the TP instrument whose public cost is lowest. Public guarantees for private loans, which involve the same allocation of risks as public loans, could have a lower public cost than public loans if the liquidity of the capital market is high.

(b) Targeting of technologies by this instrument

» *Ability to target a specific technical option:* Public loans or loan guarantees allow authorities to target a specific technology or technical option. The choice of which innovator or project company to give the loan to is with authorities, while loan provisions can specify the use to be made of funds provided.

» *Flexibility in redirecting funds to alternative projects*: Loans can lead to a financing lock-in when, in order not to write off the funds provided to an innovating entity that is not able to pay credits back, public authorities keep providing further support to avoid its bankruptcy.

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[9] When public loans are provided at an interest rate lower than the one reflecting the inherent project risk, the public sector is actually partially subsidizing this innovation. The NPV of public funds provided in this case exceeds that of the payback if a fair interest rate is employed in the computation. This situation may occur in innovation projects where market interest rates available exceed the maximum financing cost that is acceptable from the innovator’s perspective.

(c) Type of innovating entity to receive this kind of support

Public loans or guarantees are best suited to large innovating entities whose financial capability is proven or to small innovating entities undertaking low-risk, low-cost innovation.

Main conclusion

Loans are well suited to financing low risk innovation processes that are expected to yield revenues in the short-term or high risk low cost innovation carried out by large companies that can appropriate a significant fraction of the social benefits that the former produces. Public loans should be used instead of private ones if the liquidity of the capital market is too low or if public authorities are better prepared than the private sector to assess the revenues, costs and risks involved in the concerned innovation process. This may be the case of innovation processes related to activities where the public sector is very important (e.g. RD&D in nuclear). Loans can be provided both by MS and the EU.

6.2.2 Provision of publicly owned equity (PPEPs)

(a) Ability of this instrument to fund innovation at a reasonable cost

» *Size of the financing gap it is able to cover*: Obtaining a unit of equity financing is deemed to be less profitable to innovators than the same amount of subsidies. This is due to the fact that external equity financing (including public equity) entails a reduction in the revenues obtained by the innovator from the process undertaken, since these revenues must be shared between equity holders.

On the other hand, equity may be more successful than loans in closing the funding gap of risky innovation processes undertaken by small companies. Contrary to public loans, issuing equity does not create financial distress in small innovating companies, since payments from the company to investors are contingent on the success of the innovation. Apart from this, investments in the equity of small companies would provide the latter with the collateral they need to obtain further debt-based funds. Finally, public equity investments could allow the administration, together with potential private equity investors, to provide certain expertise to small innovators, which can increase the ability of the latter to succeed in the innovation process and may therefore also help to close the existing financing gap. These and other arguments on the use of equity financing in small innovating entities are discussed in Carpenter and Petersen (2002).

Big innovating entities may be better served with loans than with publicly owned equity, since the diminishing effect of the former on the revenues from the innovation process is bundled.

» *Public cost:* Revenues from an innovation process are normally shared among equity owners proportionately to equity shares. This allows the public investor to benefit from the revenues resulting from successful RD&D activities. These funds could be used to finance further innovation[10]. All this taken together implies that the public cost of the acquisition of equity shares is lower than that of the provision of the same amount of grants. On the other hand, given the risky nature of innovation activity and the lack of ability of authorities to identify winning technologies, participating in the equity of innovating entities is deemed to be more expensive from a public point of view than providing these entities with public loans.

[10] In order to make the innovation process more attractive for private equity or debt investors, public equity investments could be subject to special conditions in terms of the allocation of revenues from the innovation process.

(b) Targeting of technologies by this instrument

» *Ability to target a specific technical option*: Equity investments allow authorities to choose which innovation processes to back. By choosing which RD&D activities to support, authorities undermine competition among technologies or technical solutions, but at the same time are able to push the undertaking of socially valuable innovation processes that are not commercially appealing.

» *Flexibility in redirecting funds to alternative projects*: By providing certain expertise and being able to influence the decisions made by the managers of an innovating entity, public authorities buying equity of this entity have some control over the target of the innovation activity within the company. Therefore, they could contribute to a reallocation of funds within the company as more knowledge is gained about the potential of alternative technical options or in response to a change in market conditions, thus partially avoiding locking authorities into funding innovation activity that is not believed to deliver the initially expected results. Therefore, provided public authorities have the needed skills and willingness to operate, they should more easily redirect funds to more successful innovation processes when these funds are provided in the form of equity than when they are provided in the form of conventional subsidies or loans.

(c) Type of innovating entity to receive this kind of support

The public administration may, in principle, acquire part of the equity of both big and small innovating firms. However, when these firms are of a small size, their market value is intimately associated with the success of the innovation process to be publicly financed. Then, by acquiring shares of these entities, the public sector would be able to profit from the success of the innovation publicly funded. The profitability of public equity investments in large stand-alone project companies created to undertake the targeted innovation is also intimately linked to the success of this innovation.

As already explained in paragraph (a) of this section, loans may be a suitable alternative to equity investments in large innovating entities regarding their ability to trigger innovation activity. However, this is not the case for small innovating entities that can be financially stressed by loans.

Main conclusion

Publicly owned equity is suitable to finance innovation that is subject to a high risk of not reaching the market (early research, development or demonstration activity) but may also render high market revenues. Both equity investments in small and big entities are possible, though the former are likely to be more abundant than the latter. Given the limited financial resources available to authorities, public contributions to the equity of innovating firms should be reduced in scope and size. Thus, innovation being financed with publicly owned equity should not be capital-intensive if public equity contributions represent a major source of funds. Alternatively, public equity can marginally finance large innovation project companies, acting as a signal of the potential and quality of the concerned innovation process. Equity can be bought both by MS and EU institutions.

6.2.3 Prizes awarded to the winner of a contest

(a) Ability of this instrument to fund innovation at a reasonable cost

» *Size of the financing gap it is able to cover*: Prizes are a form of subsidy that places the technical and economic risks of RD&D activities on the innovator since the provision of public funds is contingent on the success of the innovation undertaken (see also Newell, 2007). Hence, conventional subsidies are preferred by innovators over prizes of the same size. In other words, prizes offered to undertake an innovation must be significantly larger than the unconditional subsidies that would suffice to undertake it. This implies that prizes offered to undertake costly processes would have to be very large in size. Besides, innovators involved in a contest that requires undertaking expensive innovation may face liquidity problems, since they alone have to bear the up front cost of this activity. All this advises limiting the use of prizes to innovation whose cost is relatively low.

» *Public cost:* Prizes are a form of subsidy. Therefore, their public cost must, in principle, be deemed high compared to that of loans or publicly owned equity. However, by *rewarding outputs* rather than inputs, prizes encourage the innovator to carry out its function efficiently, thus eliminating the risk of moral hazard behavior and increasing the probability of success, which ultimately reduces the public cost of supporting an innovation process. Besides, prizes normally result in contenders exploring several parallel research paths, which is highly advisable in innovation that is far from the market (involving significant risks and barriers to overcome) and could, alternatively, only be achieved by funding several research projects. Thus, using prizes to fund this kind of innovation may turn out to be economical. For prizes to efficiently trigger successful and useful innovation, they must be carefully designed based on the probability of success of this innovation, its cost and the number of contenders (see Newell and Wilson, 2005).

(b) Targeting of technologies by this instrument

» *Ability to target a specific technical option:* Given that this form of support rewards outputs, prizes avoid the need for public authorities to choose the specific technical option to support while at the same time being able to target the development of a specific technology. Prizes lead to the exploration of several research paths, while the same paths may be explored by various contenders (Newell and Nathan, 2005). Besides, innovators are not encouraged to hide any information from authorities on the relative merits of different technical options.

» *Flexibility in redirecting funds to alternative projects*: Prizes only reward successful innovation. No commitment is made a priori on any specific process. Therefore, they do not run the risk of locking authorities into funding unpromising innovation activities.

(c) Type of innovating entity to receive this kind of support

Prizes create a smaller administrative burden for the innovator than other TP instruments, thus favoring the participation of small entities in contests. However, as already explained, small entities may be especially prone to have liquidity problems when facing high upfront cost innovation.

Main conclusion

Prizes may best fund low cost innovation undertaken during the first stages of development of the corresponding technologies, when the outcome of RD&D activities is highly uncertain. Prizes may be received either by small or larger companies and can be awarded both by national and European authorities.

6.2.4 Tax credits and other benefits associated with innovation investments

(a) Ability of this instrument to fund innovation at a reasonable cost

» *Size of the financing gap it is able to cover*: Providing tax credits and other benefits associated with investments in RD&D may trigger a significant amount of additional clean innovation activity. Empirical data for the US discussed in Newell (2007) show that additional RD&D investments triggered by tax exemptions may be larger than the increase in innovation produced by an amount of conventional subsidies equal to the foregone tax revenue. According to Newell, the rate of additional clean innovation investment to private tax revenues may be as high as 1. In other words, on aggregate, all private revenues from tax exemptions would be reinvested in new innovation. Therefore, public financing innovation through tax exemptions would not be replacing private innovation funds but supplementing them (even taking into account that additional tax cuts would be obtained from further investments in innovation).

However, under tax exemption schemes, the decision on which additional innovation to undertake is with incumbent innovating entities. These are the entities that can benefit from tax exemptions, since they are the ones already investing in innovation. Incumbent innovating entities (normally large companies) have traditionally shown a tendency to undertake close to the market processes that are able to render revenues in the short term. Thus, it is unlikely that private revenues from tax credits will fund a significant amount of new research and early stage development and demonstration.

» *Public cost:* Tax credits are a subsidy of the size of the tax revenues foregone by the public administration. Their cost is deemed to be higher than that of public loans or publicly owned equity. However, as explained above, this type of instruments is less likely to crowd out private investments than conventional grants, since tax credits are granted on the condition of private investments in innovation already taking place. Therefore, the ratio of the total amount of investments in innovation triggered to the amount of public funds provided is deemed to be higher than that for conventional subsidies. In other words, the public cost of innovation triggered by tax credits is thought to be lower than the cost of innovation funded with conventional subsidies.

(b) Targeting of technologies by this instrument

» *Ability to target a specific technical option*: This type of support leaves the decision on which processes to finance in the hands of incumbent innovating entities. Tax credits create competition within each innovating company among the different innovation processes that can potentially be internally financed. Hence, targeting a technology or technical option through this instrument is not possible. Experience shows that, when left to decide, innovating entities tend to finance innovation that is close to the market (affecting mature technologies)[11].

» *Flexibility in redirecting funds to alternative projects*: Given that innovating entities, instead of public authorities, are the ones deciding on the processes to finance, and assuming that private entities are more agile than the administration in redefining investment priorities, tax credits should be more flexible than conventional subsidies in targeting successful innovation. However, this may not be a priority if processes financed through tax credits belong, almost exclusively, to the last stages of the innovation chain. Tax credit policies should represent a credible long term commitment if they are to trigger a significant amount of additional private investments.

(c) Type of innovating entity to receive this kind of support

If structured as tax exemptions, this type of support can only be deemed an option for innovating entities paying a significant amount of taxes, i.e. large companies. If other benefits, like rebates, are provided, smaller innovating entities could probably benefit from them as well. In any case, these benefits are mainly effective to support innovation by medium to large innovating entities, since an entity must already be conducting innovation in order to get them. Large entities are best suited to undertake incremental innovation, though they can also undertake very expensive radical innovation within a collaborative financing scheme. However, in order for these companies to voluntarily contribute to large (i.e. costly) radical (i.e. very risky) innovation projects, further support measures beyond tax credits may probably need to be put in place.

[11] In order to counter incentives to undertake close to the market innovation, authorities may consider the possibility of limiting the provision of tax revenues to a certain type of innovation. However, by directing the choice of processes to support, the public sector may end up picking winners, which is to be avoided.

Main conclusion

Tax credits and other benefits associated with private innovation investments are best suited to finance close to the market, incremental innovation that would, nevertheless, not be undertaken in the absence of direct public support. These processes typically are undertaken by big entities. The application of tax credits is restricted to national authorities.

6.2.5 Subsidies (grants, contracts)

(a) Ability of this instrument to fund innovation at a reasonable cost

» *Size of the financing gap it is able to cover*: Grants and contracts directly (co-)financing an innovation process probably are the only type of public support capable of engaging innovating entities in expensive early research not undertaken under a cooperative scheme. If the award of grants or contracts does not affect the ownership of intellectual property resulting from innovation, these instruments are most profitable for innovators. In this case, subsidies reduce the fraction of the project costs born by the innovating entity, including upfront costs, while not reducing its revenues from this project. If the award of grants and contracts prevents the innovator from patenting the results of the subsidized innovation project, the profitability of this project for the private sector may get significantly reduced involving that a larger fraction of the cost of the project might have to be subsidized. If the level of a subsidy depends on the outcome of the project supported, its attractiveness to innovators may be reduced as well.

» *Public cost:* Unconditional subsidies are the direct support instrument whose cost for the public sector is highest and which furthest erode the capacity of authorities to support further innovation. The provision of public funds to finance a process is not partially offset by any kind of compensation received by the public sector[12]. Furthermore, grants and contracts may lead to moral hazard behavior once funds have been provided. Therefore, if possible, subsidies should be designed such that any waste of public money is avoided, which can be achieved by linking the provision of funds to the achievement of intermediate and final project objectives measured via Key Performance Indicators. This should lead to a step-wise provision of funds and the early termination of those projects that are unsuccessful.

(b) Targeting of technologies by this instrument

» *Ability to target a specific technical option:* Using subsidies, authorities are able to target any kind of innovation process, including those that are less commercially appealing. However, when subsidizing innovation, authorities must identify winning technologies (they must actually target a specific process or set of processes), which, as already explained above, may be a source of inefficiencies[13]. Consequently, the use of subsidies to fund technologies that are able to compete with alternative clean options and, therefore, do not need to be targeted by public support, should be avoided.

» *Flexibility in redirecting funds to alternative projects*: When a significant amount of public funds has already been invested in an innovation process, authorities may decide to continue supporting this process only to avoid the perception that they have wasted those funds already spent. Therefore, the

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[12] The case where authorities get some rights over the outcome of the innovation process is an exception.

[13] Given that authorities are normally not well suited to picking winners, the fact that they have to choose which processes to subsidize may lead to two types of undesirable effects. First, private investments may be crowded out if subsidies are provided to projects that would otherwise be financed by private parties. Second, due to the inability of authorities to precisely assess the social potential of innovation processes and encourage efficiency in their management, the share of failed innovation projects that are subsidized is likely to be higher than that for projects receiving other forms of public support.

use of subsidies may lock authorities into supporting processes whose techno-economic results obtained thus far are not good.

(c) Type of innovating entity to receive this kind of support

In principle, grants and contracts can be granted to any type of innovating entity.

Main conclusion

Grants and contracts should only be awarded to innovation processes with a high potential social value which would otherwise not be carried out because they are not commercially appealing. This is the case of innovation involving clean energy technologies in the early stages of development, facing significant technical/regulatory barriers or producing benefits that can easily be appropriated by competitors of the innovator. However, a major part of clean energy innovation exhibits these features. Subsidies can be awarded both by national and European authorities.

6.2.6 Notes on the combined use of TP instruments

Public funds supporting an innovation process may be provided through several instruments. Thus, for example, publicly owned equity can mix well with loans to support the activity of small innovating entities. As explained in Section 6.2.2, equity can provide a small entity with the collateral it needs to get debt-based financing. However, we have also argued that financing innovation by small entities using a significant amount of loans may cause financial distress in these entities in the presence of a backlash in research.

Other plausible combinations of instruments are that of loans with subsidies or that of publicly owned equity and subsidies. Public loans subject to interest rates that are below those offered in the market by well informed private lenders are in reality a combination of a loan and a subsidy. Publicly owned equity may be combined with subsidies to allow the public administration, and therefore society, to take a participation in revenues from innovation that needs to be subsidized. An in-depth analysis of these and other combinations of instruments will be provided in future research work.

Table 1: Summary of the characteristics of Technology Push instruments

Instrument Features \ Instruments		Public loans/ loan guarantees	Publicly owned equity	Subsidies		
				Prizes	Tax credits and other benefits related to RD&D investments	Grants and contracts awarded ex-ante
Ability to trigger innovation at a reasonable cost	Size of the financing gap it is able to cover	Lower than subsidies. Bigger than publicly owned equity for large innovating entities	Lower than subsidies. Bigger than public loans for small innovating entities.	Medium. Able to fund low cost early research but not expensive innovation	High. However, only applicable to close to market innovation	Very high. Capable of engaging innovators in any kind of process
	Public cost	Very low	Lower than for subsidies	Medium	Relatively high	High
Targeting of the technology	Able to target a specific technology	Yes	Yes	Yes	No	Yes
	Flexibility in redirecting funds	Low	Relatively high	Medium	Relatively high	Low
Targeting of the innovating entity	Type of innovating entity well suited to receiving this support	Large entities with proven financial capability or small entities addressing low-risk innovation	Small entity or project company	Any (more suitable than other options to small entities when investments to undertake are small)	Addressed at large innovating entities: 1) Pay large taxes; 2) Already performing RD&D	Any
Conclusion Type of innovation processes that are well suited to be supported by these instruments		1) Low-risk innovation; 2) Risky, potentially profitable innovation by large firms. Only if illiquid capital markets or little private expertise	Low cost innovation whose risk of failure is high and that is carried out by small innovating entities	Low cost innovation processes involving a large amount of applied R&D	Processes in the last stages of the innovation chain carried out by large entities (incremental innovation)	Processes in the early stages of innovation, facing significant barriers and spillovers

7 Summary and conclusions

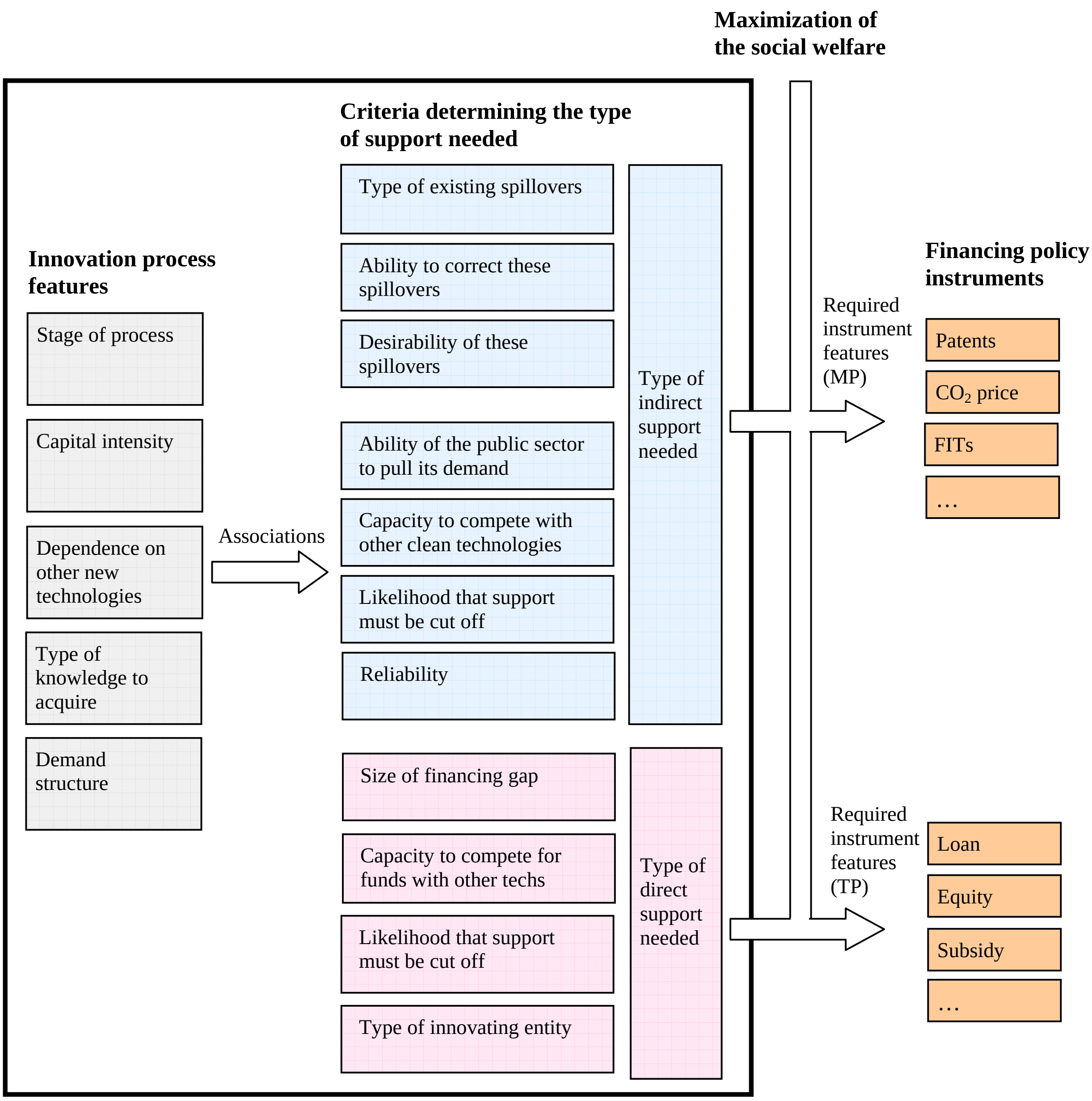
Market Pull instruments are not able to completely correct the spillovers of benefits produced by clean energy technologies. Neither can they address all the existing barriers to the penetration of these technologies. Therefore, mobilizing public funds to support clean energy innovation is also necessary. Indirect and direct public support instruments are complementary means to trigger innovation.

Public support provided should match the features of the innovation process addressed while maximizing social welfare. This determines the characteristics of financing policy instruments to be used. Instruments directly funding clean energy RD&D (i.e. Technology Push) should be able to engage innovators in those activities with the highest social value at the lowest possible public cost. When allocating public funds, authorities should achieve the right balance between the selection of the technologies to back and the creation of competition among them while being able to easily redirect funds to other technologies whenever necessary. Lastly, Technology Push instruments should be well adapted to the type of entity that is likely to conduct the innovation concerned.

Awarding contracts and grants before innovation is undertaken may be necessary to engage private entities in expensive research that is socially valuable but whose commercial appeal is very low. If the targeted innovation is far from the market but relatively inexpensive, output-driven direct support in the form of prizes can provide adequate investment incentives. Early inexpensive research can also be supported through publicly owned equity investments when it is to be conducted by small entities or project companies. Meanwhile, public loans or loan guarantees could support this type of research if it is to be conducted by large companies and the public sector is very important in the relevant research area or if the liquidity of the capital market is low. Public loans can also fund close to the market innovation (both capital-intensive and not) in the aforementioned conditions. Finally, close to the market innovation in areas where well established big firms are very active is best supported through tax credits or other benefits associated with private RD&D investments.

Figure 2 summarizes the selection of both Market Pull and Technology Push instruments according to the methodology presented in this paper.

Figure 2: Matching of an innovation process with financing policy instrument(s)



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