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Building a Portfolio of Pull Financing Mechanisms for Climate and Development

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Abstract

Pull financing is a powerful but underused mechanism for incentivising progress on hard-to-tackle social problems for which innovation or the take-up of innovation may be part of the solution. It should become part of the ongoing landscape for climate and development work. This paper sets out the specific design features for a portfolio of pull financing mechanisms to support the accelerated development of socially valuable innovations with both climate and development implications. It considers the institutional structure required to manage such a novel mechanism, a process for finding and developing a potential application, and the objectives pull financing should pursue. It then looks in detail at seven applications of pull financing in the climate and development space, each selected to illustrate the potential and challenges of the approach. We conclude by setting out how to construct a high-ambition portfolio of pull financing projects that is both tractable and attractive to potential funders.

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Introduction

The challenges of climate change can manifest very differently in poorer countries, and the means to respond effectively are less likely to be provided by the market because the private returns to doing so tend to be small. This makes the development of pull mechanisms to bring new technologies to the market and to scale and drive down the cost of existing technologies a theoretically attractive proposition (Dissanayake, 2021). However, lessons from past applications suggest that the success and efficiency of pull financing depend greatly on the details of the specific application to which they are applied and the technological, contracting, and monitoring details of the arrangement (Advance Market Commitment Working Group, 2005; Kremer et al., 2020). This note deepens the case for pull financing for climate technologies and provides some of the details required to design and implement such mechanisms successfully. Specifically, we discuss how potential applications for pull financing can be discovered and developed as well as the institutional and financing requirements for setting up a portfolio of climate/development pull financing arrangements. We then examine seven possible applications, setting out the potential scale of benefits, their likely cost, and the contracting and technological barriers that remain to be resolved.

We build on a recent Center for Global Development paper (Dissanayake 2021) in assessing each candidate's application on the following five grounds to the greatest extent possible:

- The *magnitude of development gains* from resolving the identified problem that accrues to the developing country directly, and for official development assistance (ODA)-eligible financing, the proportion of those gains would accrue to those living in poverty. These gains can include benefits of adaptation to climate change since the failure to adapt to changing climate implies worse development outcomes.
- The *size of the climate or environmental externality* generated by take-up of the innovation for those interventions with a climate mitigation (as opposed to adaptation) purpose.
- The *distance to market* of acceptable solutions and the technological hurdles to be cleared before each. A greater distance to market requires more funding and entails more uncertainty as to the nature of the solution. This does not necessarily make such interventions less attractive, but it does change the nature of the incentive required and how well it fits with other pull mechanisms as part of a portfolio.
- The realistic *maximum achievable scale* of a solution, which determines (together with distance to market) the necessary size and time horizon of the pull mechanism.[1]
- The *availability of appropriate metrics* and the contracting problems that remain to be resolved in each sector.

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[1] If its aim is to directly incentivise large scale take-up. Some pull mechanisms may simply aim to incentivise sufficient supply to change production costs or to have a demonstration effect.

The applications we investigate in this paper are the development of more stress-tolerant or less resource-intensive crops; better, more granular weather forecasting for underserved areas; eliminating crop-residue (stubble) burning; development and use of cleaner and greener cooking systems; green and affordable residential, public, and commercial cooling; less carbon-intensive and higher-quality road sealant materials; and the development of electric vehicles suited for developing country (and specifically African) markets.[2] These applications are selected for convenience: they are well known and developed enough to investigate deeply and provide clear examples of the kind of problem pull financing can be used to address and the advantages and difficulties of using pull financing in specific cases. They are not intended as a definitive list of the most promising candidates for pull financing in the climate and development space. We discuss how they were selected and the need for a more comprehensive and rigorous selection process, and particularly, the importance of investigating less well-developed or understood problems. However, each of the applications we discuss in this note has the potential to achieve a high impact over a large scale. They serve as a good starting point from which to discuss the potential of pull financing in this sphere as well as the problems they will need to navigate.

In forthcoming analysis, specific designs for pull mechanisms to stimulate progress on stubble burning and green cooling mechanisms are developed (Stephens et. al., forthcoming). These serve as potential templates for implementation and demonstrate how such a mechanism would operate in practice and can be used by donors as a starting point for creating such a system.

This paper proceeds as follows: we begin by briefly setting out key design questions and features for a portfolio of pull financing mechanisms—specifically, its institutional form, its resourcing requirements, what it will seek to achieve, and how it can be structured to continually unearth the best and most promising applications and problems to support—before discussing seven potential applications in depth to illustrate the potential of such a mechanism and the kinds of problem it will need to resolve. We conclude by briefly discussing how a portfolio should be constructed from the potential applications unearthed.

Designing an Effective Pull Financing Vehicle

Finding the right institutional form

We propose that pull financing become part of the ongoing landscape for climate and development work. For this to happen, three requirements must be met: it needs to be managed by a suitable institution (or set of institutions, though we suggest a single, specialised institution); it needs to be sufficiently well-financed; and there needs to be a steady pipeline of ideas.

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[2] Not all of these are exclusively African or low-income country problems.

An institutional form that meets all these criteria does not already exist,[3] so one needs to be created, whether in the form of a new, standalone institution as part of a Multilateral Development Bank trust fund or as an appendage to an existing institution. The problems pull financing projects need to solve and the expertise required to solve them are somewhat different (or at least different in emphasis than most conventional programmes; what's more, the expertise required to resolve these problems depends on the specific applications being pursued at any given time; a sufficiently broad portfolio of mechanisms means any institution managing the portfolio needs access to an unusually broad range of expertise.

Flexibility of staffing is the second key point required for the right institutional form for an extensive pull financing system. The right institution is unlikely to optimally function without the capacity to engage contracting and technical specialists on a project-by-project basis or alternatively, to subcontract the implementation of specific mechanisms to existing specialist institutions with the right expertise, should they exist and have the capacity to manage them.[4] A small standing staff and a senior secretariat will also be required. This in turn suggests the third characteristic of a viable pull institution: it needs to have the convening power and network to attract sufficient expertise at both technical and leadership levels.

Finally, an institution devoted to pull financing requires financial flexibility. It will, by definition, be unable to schedule disbursements to recipients at regular intervals, depending, as they do, on performance against targets or objectives; there is also a risk of nonperformance and thus, nonpayment. While these risks can be mitigated using a broad portfolio, promissory notes to guarantee funding, and similar mechanisms to reduce budget uncertainty, some level of financial flexibility (and security—for a demand pull mechanism to work, it must have absolute credibility on payout and be fully funded for all of the mechanisms that form part of the portfolio[5] will be unavoidably required.

That an institution meets all these requirements does not yet exist is one reason why pull financing is relatively underutilised. Beyond its institutional characteristics, the institution's financial power and what it seeks to achieve with pull financing are also critically important. We explore these issues more fully in an accompanying blog.

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[3] MedAccess has a structure rather similar to what we propose here though focusing on medical industry volume guarantees.

[4] In practice, one can easily imagine that some mechanisms would be subcontracted where existing institutions have the appropriate skills and mandate, while others would be implemented in-house. For many applications, there may be no existing institutions with sufficient expertise. This is particularly likely to be the case for pull financing mechanisms, given that they tend to focus on problems for which few or no existing solutions exist.

[5] For any pull mechanism or results-based financing mechanism to be credible and attractive, potential innovators or suppliers of the service or product to be purchased must have confidence that payment will be made when results are achieved. That may mean insulation or insurance against unexpected cuts in donor funding or the need for a large portfolio of diverse funders to reduce the risk of any single funder cutting budgets.

Mobilizing sufficient resources

There are three key considerations in terms of how much funding a portfolio of pull financing mechanisms will need: the number of individual mechanisms funded, driven by funder appetite and the need to construct a sufficiently diverse portfolio to mitigate delivery risks; meeting the minimum market-moving level for each pull mechanism; and setting a sufficiently ambitious set of targets. All suggest that a too-small financing allocation is a bigger risk than one that is too large.

For any pull mechanism to work, it needs to be sufficiently large to move the market for the technology or product it covers. For each mechanism, the reward on offer needs to be sufficient to cause innovators, producers, and investors to reallocate their effort and their funding towards the problem targeted. Underfunding a pull mechanism is fatal to its chances: if the incentive offered is insufficient to induce substantial innovator effort, the mechanism will either achieve nothing or only marginally increase the speed with which technologies are developed and deployed.[6] That means the effect of a pull mechanism is likely to have a discontinuous likelihood of success around some threshold for shifting incentives of major actors.[7] If too much money is allocated to a mechanism the primary risk is overpaying for results, though this can be capped at the estimated social benefit or funders' willingness to pay for a specific impact; however, if too little is pledged, there may be no real additional innovative effort and no social benefit achieved at all. These risks are asymmetric from a social benefit perspective.

The other resourcing consideration is where the level of ambition is set. A portfolio of mechanisms limited to using aid money (ODA, specifically) would be constrained on the climate side by development impact—that is, it would be unable to pursue some highly effective climate technologies for want of demonstrable payoffs to developing countries specifically (this is a concern addressed in Dissanayake, 2021). Even so restricted, a pull institution can set its sights high by pursuing, for example, multiple seed varieties across the globe at a massive scale of take-up as well as other potential technologies.

However, if a new pull financing institution can administer both aid and non-aid contributions, its scale and ambition can be many times larger. Many important climate mitigation problems for which technological advances may be required to solve are primarily developed-country problems, even if applications can also be used in developing countries. Solutions to these problems should not

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[6] Underfunding of a pull mechanism can happen in two ways: it may offer a level of funding that is too small per result and thus attract only a few actors—or none at all—into the market. Alternatively, it may offer an adequate per-result amount but be too small in aggregate, so it either remains unattractive to some actors or incentivises only small increases in supply. A similar logic applies to the time frame over which the funding is available: too short and it may not incentivise significant investments in production capacity or search for better technologies.

[7] This discontinuity may take many forms, which are not mutually exclusive. There may be a switching point for innovator effort below which new innovators will not enter the market; there may be nonlinearities in production functions, which means that cost changes substantially above a certain level of production; or there may be nonlinearities in the likelihood of success in technological innovation with respect to the number of innovators induced to enter the market.

primarily (or largely) be funded from aid since the benefits will primarily accrue to nonpoor places. What's more, since rich countries and large industries are already active in these areas, the financing required to move the market is much larger than it is for problems that primarily affect poorer places[8] and thus attract less investment. Frontier, the advance market commitment (AMC) set up by Stripe to stimulate better and cheaper carbon removal technologies, is worth close to $1 billion, for example. Since energy use and emissions are highest in relatively richer places, globally ambitious climate pull financing needs to be more than aid and development spending and consequently needs to be much larger than any of the applications proposed here, which are limited to those with a viable development angle.

Pull for technology and pull for scale

Pull financing can thus be designed to shift the economics of innovation in three ways: to incentivise the (faster) development of new technologies, to derisk up-front investments in manufacturing capacity,[9] and to incentivise investment in the whole technological chain from idea to widespread use. Classic treatments of AMCs (such as Barder, 2005) focused on the role of pull financing to incentivise innovation where a problem or adaptation was specific to poor countries, though the logic extends to any market where the private market size is insufficient to incentivise adequate innovator engagement to solve the problem as quickly as is socially desirable. Earlier pull financing mechanisms (such as the Longitude Prize) focused solely on the technology desired and not at all on the scale of production of the solution.

In practice, however, contracts written in support of pull financing may, and often do, specify a minimum scale for the deployment (and may also be capped, so support 'expires' after a specific scale is achieved). The pneumococcal AMC was structured in this manner with an additional subsidy for the first 20 percent of doses produced per manufacturer (Cernuschi et al., 2011). This structure is similar to outcome-based financing and payment-by-results but may be used not only to incentivise the full range of activities—from innovation to take-up—but to also derisk the investment in manufacturing and deployment capacity (which may be a significant brake on the speed of deployment), thus speeding up entry into the market. In this manner, pull mechanisms can also drive down costs and eliminate the need for subsidy over time.

The applications investigated in this paper suggest some use of each of these three design features.

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[8] Throughout this paper, by "poorer places," we mean places with a substantial burden of poverty as measured by the World Bank's $1.90 a day in purchasing power parity (PPP) poverty line. This is a stricter definition than implied by the Organisation for Economic Co-operation and Development (OECD) Development Assistance Committee's (DAC) ODA eligibility list, excluding some lower as well as most upper-middle income countries. In these places, ODA tends to be a much smaller proportion of the gross domestic product and consequently typically has less transformative potential (see Dissanayake et al., 2020; Dissanayake & Tahmasebi, 2021; Kenny, 2021). The converse is also therefore true: when we talk about "relatively richer places," we include most UMICs and many LMICs.

[9] This applies by guaranteeing a certain market size if conditions are met. This makes derisking more indirect than with push financing, but it has advantages in not requiring that funders 'pick winners' in the innovation race.

Picking the right applications

Pull financing can either pursue a single specific problem or a general class of problems: either an efficacious and cost-effective vaccine for a specific strain of disease or the development of vaccines for a class of disease prevalent in poor countries, for example. The great advantage of the former approach is that it simplifies and rationalises the technical and contracting expertise required to design the vehicle by focusing on one specific contract for one specific problem. The advantage of the latter is that it allows more ‘shots on goal’ at a large and important class of problem.

In tackling climate and development problems, we lean towards the latter approach for two reasons. First, the category is broad enough that it encompasses very different applications, each delivering benefits to different groups of people in different regions with a different balance between climate and development gains; equally important, the technological barriers to a solution are not equally tricky. A portfolio has the potential to deliver benefits broadly and maximise the chances of a meaningful ‘hit.’ On the other hand, there are not so many climate (mitigation) and development win-wins that the contracting and technological problems are so diverse that no single body could administer many of them at once.

Constructing an effective and efficient portfolio requires both selecting viable applications and determining which have the right mix of potential benefits, likely cost, and timelines for delivery to represent a logical bundle. We focus on selecting viable applications here, though the final section briefly discusses how portfolio construction might be addressed.

In what follows, we investigate seven possible applications for pull financing with both climate and development objectives. However, as discussed above, these seven applications are in no way intended to be exhaustive or even the best seven possible applications. Climate and development are both extremely large fields; there are many ways in which technological solutions may support one or both (remembering that technology does not necessarily just mean a new gizmo or machine; it could be a new way of organizing existing resources or a new way of monitoring how we work or share information).

As such, one of the key ongoing activities a new pull financing institution must engage in is the continued search for potential applications. Such a search needs to cast its net widely: no individual or group is likely to have a good grasp of the full set of problems that require new solutions in development or climate spaces. A model that encourages the sharing of early-stage ideas and supports their development is likely to bear more fruit than one that is limited to only relatively well-developed applications, as are the majority set out here. One such process would consist of:

- **Crowd-sourcing ideas through a simple, informal call for submissions.** Ideas could plausibly come from an individual, group, or nongovernment organisation that deals with a specific problem they would like fixed; from innovators or technology experts who see a possible new application for an existing technology (perhaps after some adaptation); or from a subject expert who can identify where there is an existing need but no way to corral demand for it.

- **Assessing ideas on social welfare and contracting grounds.** An assessment board made up of scientists and technical experts (including from industry and commerce) as well as social scientists (including economists) and procurement experts could judge the merits of each proposal. It would need to move quickly and announce awards fast: enthusiasm for the format must be maintained. A prespecified deliberation/decision structure could be adopted.
- **Making a scale of awards available.** Such awards would include small push finance to find the right people to develop the idea further and to fund them to develop the idea until some contracting framework can be designed. It could then switch to push/pull (e.g., grants to five candidates to cover early incurred fixed costs and pull financing to cover variable costs of production) to test the concept before graduating to a full-sized pull mechanism.

However structured, the general point is that a more comprehensive manner of identifying opportunities is required for a stable portfolio of pull mechanisms, and such a process needs to draw on and incentivise the engagement of widely dispersed expertise. The rest of this paper investigates seven specific applications already identified and concludes by discussing how a portfolio of applications might be managed.

Applying Pull Financing to Climate and Development: Examples

This section discusses several potential applications for pull financing, the development and climate benefits they might bring, how pull financing can improve outcomes, and the contracting difficulties that remain to be resolved before they can be successfully implemented. Though the focus here is on the specifics of how the funding agencies and a pull financing institution can affect the incentives of private actors to accelerate change, in many cases government action is also required through regulatory change or enforcement, through the provision of complementary public goods, and so on. The focus on the details of a pull mechanism should not obscure the central importance of the broader policy environment; ultimately, the success or failure of any specific mechanism will depend in part on local public sector actors; in final decisions around applications, explicit judgments will need to be made as to where the minimum policy shifts to support the objectives of the pull mechanism are more likely. While such considerations are largely beyond the scope of this paper, where they are of first-order importance, they are considered. However, in the final design, a deeper consideration of governmental action required should be made.

New crop varieties

The case for intervention

Agricultural productivity is highly susceptible to climate change, and research and development focused on (in particular) African agriculture has suffered from years of dramatic underinvestment. Though levels of investment per farmer are increasing, Suri & Udry (2022) note: "the lack of productive new technologies ready to be adopted in Africa is no mystery: it's the result of low levels of agricultural research and development investment in the past." The development of new seed varieties that cope better with climate stress and are more sparing in their use of scarce natural resources is one such under-invested in technology that could generate large welfare gains. Green revolution technologies have had astoundingly large aggregate benefits (Gollin et al., 2021), but the gains were unevenly distributed with Africa left relatively behind. Developing new varieties specifically for Africa is thus attractive, but the challenges in using a pull mechanism to do so also clearly illustrate the challenges inherent in their design. Stress-tolerant seeds—and particularly those designed for adoption in marginal, rainfed areas—require both technological innovation and some structure incentivising design aimed at final market take-up. As such, we care about not only their technical (lab and demonstration field) properties but also their performance in the rarely optimal real-field conditions where they may ultimately be used and in turn, their desirability and take-up by end users. Each of these spheres of performance depends on a progressively larger (and progressively harder to define) set of characteristics. This makes the design of appropriate metrics and an appropriate contracting structure difficult but not insoluble, as we discuss below.

The development of new seed varieties suited for changing climatic circumstances and capable of increasing agricultural productivity has extremely large potential development gains. They can partially stabilize yields during climatic extremes, which are becoming more frequent, and increase the resilience of cropping systems to climate-related risks, especially in tandem with the take-up of other technological innovations for agriculture. The net effect could be a substantial increase in productivity relative to its counterfactual trend. There is a substantial body of research that has quantified the gains from seed variety development in response to other challenges. Subramanian & Qaim (2009) tested the impact of Bt cotton[10] on poor households in rural India and found that its adoption increased returns to labour, especially for hired female workers. Likewise, aggregate household incomes rise, with gains extending to the poorest and most vulnerable framers in the study. In an unrelated application, a recent World Bank-funded programme in Samoa found that improved vegetable varieties improved productivity in the field. More broadly, a joint Food and Agriculture Organization (FAO)/International Atomic Energy Agency (IAEA) report (though focused on Asia) estimates the benefits of developing new crop varieties as between €7.5 m and €23.2 m (IAEA et al., 2020). The study reported an average cost-benefit ratio from the development of new varieties in the past of 11.1:1, with a range from 5.8:1 under the most pessimistic scenario that it was

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[10] Bt cotton is a genetically modified, pest-resistant plant cotton variety.

considered to 15.9:1 under the most optimistic scenario considered for the report.[11] In particular, it found new varieties contribute to a 32.7 percent increase in overall productivity and enhanced environmental protection with substantial reductions in the use of agricultural outputs. Given the much lower agricultural productivity in much of Africa (Gollin, 2021; Nin-Pratt, 2015) and its high risk of climatic variability (WMO, 2020), these returns are likely to be even larger there. Climate and environmental impacts depend on the variety developed. Bt cotton studies found that negative externalities on the environment are significantly lower in Bt cotton than in conventional cotton (Veettil et al., 2017). Bt cotton adoption also contributed to higher environmental efficiency by reducing the use of pesticide sprays and reducing the pest cotton bollworm on other crops (Qaim et al., 2006; Thirtle et al., 2003).

What's more, there is potential to apply novel methods to the development of new seeds. Advances in machine learning, for example, could speed up the crop development process and develop portfolios of crops that can adapt successfully to climate change (Bari et al., 2021), which suggests that there remain substantial untapped benefits from the development of new seeds and crop varieties.

Designing a pull mechanism

If the benefits are so large, to the extent that it seems impossible to overpay for better seeds, one might reasonably ask why a pull mechanism should be employed at all: push financing for several promising candidate technologies will likely still generate a positive return even if most support recipients fail. The case for pull financing lies in the fact that seed varieties and crops must not only have beneficial resource-use characteristics or productivity characteristics but must also be user friendly (at farming, transport, and marketing levels) and meet minimum standards on other dimensions that may be harder to specify, such as flavour and appearance, and for which a range of plausible effective (and ineffective) combinations are possible—most of which are difficult or impossible to predict. Push financing is adequate for meeting the easily specified and well-known requirements, but those that determine take-up are less so.

As such, a financing mechanism that rewards both the resource-use or productivity characteristics and end-user take-up and repeated use is required, without rewarding either one so extensively that the other can be ignored. As such, it should induce both technological innovation and effort to reach consumers. For example, a funder could provide some portion of the R&D costs less than 100 percent to innovators, with at least some of this grant paid only upon the results of lab trials or demonstration field trials. At the same time, it could offer some sufficiently small per-purchase or use payment to incentivise investments in usability and take-up. The first component would be paid to innovators/wholesalers directly, upon demonstration of seed characteristics; the second component could be paid on either verified retail sales (requiring an independent third-party verifier) or on wholesale

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[11] These estimates can be found in the report and are based on outcomes under the Regional Cooperative Agreement between 2000 and 2019.

purchases by retailers over a certain number of years (ensuring that retailers continue to purchase the seed, signalling success in marketing). This leaves some demand risk to producers but also an incentive to invest in user-friendly and popular seeds. In sum, an innovator would only recoup costs fully and make sufficient profit if it was able to meet both the technical standards set out for resource-use and productivity characteristics and to reach sufficient scale in take-up (with sufficiency dependent on the characteristics of the seed, the number of potential end users of an effective new variety and the scale in production required to drive costs down—which for seed varieties tends not to be a factor since the marginal cost of production is negligible compared to the fixed costs of R&D). What would these costs be? Lassoued et al. (2019) found that the expected costs of new crop varieties or genome-edited crops are case specific and depend on each crop and whether these crops will be regulated as genetically modified (GM) or accepted as conventional varieties and therefore not subject to additional regulatory oversight by federal regulators. For example, experts believe that genome-edited crops might be able to reach the market at lower costs (US$10.5 million) and in a shorter time (five years) compared with innovations regulated as GM, in which case costs would be around $25 million and the time frame closer to 14 years.[12] These estimates provide an upper bound on any fixed grant component of a pull mechanism, which should not meet all these costs. These costs are additional to regulatory costs and other institutional hurdles that must be cleared before marketing (Smyth 2017). Spielman & Smale (2017) suggest a sequence of regulatory reforms and public investments to accelerate the achievable scale.

The true pull component is harder to estimate. The size of the market for seeds in Africa is large and consists of an informal system of seed development, production, and distribution centred on smallholder farmers and a formal market that is regulated, with key players including governments, private companies, research institutes, and civil society organisations. The value of the commercial seed market was estimated at around $1.9 billion in 2021, with the precise structure of the market varying substantially by country. Nevertheless, in most cases, commercial seed providers have failed to substantially penetrate the smallholder market, and rates of variety turnover and seed development remain low.[13] A successful pull mechanism would, in part, incentivise firms (and other actors) to reach smallholder farmers much more successfully.

A per-user payment could do this. It could either be a price subsidy to reduce the cost to end users or a small per-user payment to the innovator or distributor, depending on whether the constraining factor is on the farmer side, such as seed cost, or on the innovator/distributor side—for example, insufficient financial return to investing in outreach. The size of the payment depends on both how much of a subsidy is required to encourage take-up (or effort to reach smallholders) and how large the potential market is (and what level of penetration of this market would constitute success). Since small-scale farmers in Africa are most vulnerable to increased climate variability, the potential

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[12] The study also suggests that there is a difference if it is regulated in the US or Europe.

[13] This section draws on IHS Markit analysis (https://ihsmarkit.com/research-analysis/commercial-seed-markets-in-africa-2021.html).

market size could be as high as 30 million farms, though the volume purchased per farmer would be small (the potential market size for more resource-sparing seeds is larger still, essentially including all farming operations in Africa).[14]

If a pull mechanism for any given seed aims to reach a substantial portion of the market—say one million farms—and a per-user subsidy (or take-up payment) of between 10 and 50 percent of the commercial seed cost (or, more specifically, the difference in the cost of modified versus conventional seed) is needed to incentivise effort to promote take-up, a conservative estimate of the cost would be around $5–$25 million, per varietal covered.[15]

How innovators achieve take-up should be left unspecified (though predatory practices explicitly ruled out). Dar et al. (2019) suggest that demonstration plots are an effective way to encourage the spread of information about new technologies (such as new crop varieties) in agriculture by encouraging interactions between farmers; another approach might be more targeted outreach. Ultimately, what funders should be concerned about is that the new varieties have desirable properties and that farmers use them voluntarily and regularly enough to realise their benefits.

The size and structure of a mechanism to incentivise the rollout of new seeds and crop varieties will depend, in part on the distance to market of the portfolio of seed types covered. Some, like Bt cotton, are already developed and have been adopted in some locations; the challenge may be to scale-up adoption (including any technical tweaks required to suit variability in local conditions). For other crops that have not been tested (varietal development), the distance to the market is longer, and relatively more effort is required on the innovation side compared to the take-up side. A pull financing mechanism could help both varieties in different ways. For varietal development, it could help the creation of more environmentally efficient and productive crops, and for existing varieties, it could focus on scaling and extending the use of these. A pull mechanism working on a portfolio of seeds at varying distance to market but with each one aiming to achieve a scale of one million or more farmers would likely cost in the region of $50–$100 million.[16]

The metrics used to assess performance against the contracted requirements will vary. The climatic, resource-use, and productivity profile of new seeds or crop varieties can be directly measured in an agronomic trial or farmer randomized control trial (RCT) (or both). For scaling and take-up, a choice will have to be made: sales are easier to monitor and plausibly related to use but tell us relatively less about use and repeated use, which are better indicators of the extent to which the new crop changes practices and increases welfare. Use can be measured directly but at a much higher cost. An

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[14] The International Fund for Agricultural Development estimate 33 million smallholder farms in Africa

[15] The calculations here assume take-up of around one million farmers and a subsidy of between $5 and $25 per bag of seed.

[16] As such, a pull mechanism focusing solely on seeds could also function as a portfolio of smaller pull mechanisms, though some risks across the mechanisms would likely be highly correlated.

intermediate option is to reward repeat purchases of seeds (assuming seeds need to be bought for each harvest cycle).

Taking the foregoing analysis together, it is clear that there is enormous potential value in new crop development. While designing a pull financing mechanism to incentivise new efforts in this space will be risky due primarily to contracting difficulties, it remains one of the most attractive propositions for pull finance.

Weather forecasting

The case for intervention

The development of new seeds may be used, in part, to mitigate climatic changes that reduce farmers' productivity and increase output variability. Short- and medium-term weather uncertainty also imposes substantial costs on farmers, even controlling for the quality and resilience of the crops they plant; new crop varieties may not mitigate climate-related risks and indeed may introduce new vulnerabilities while pursuing other benefits. In theory, forecasts should be complementary to technologies that insure farmers against certain shocks, such as flood-tolerant seeds, because they provide information about the likelihood of those shocks and hence the expected payoff to adoption in a given season. In India, for example, farmers who misjudge monsoon onset may be forced to replant or even abandon their crops entirely; the reliability with which they can predict weather conditions is therefore of paramount importance to their productivity (Gine et al., 2015). With climate change, weather uncertainty is increasing (Scher & Messori, 2019), which in turn imposes even greater costs on farmers.

In most developed countries, a range of differentiated commercial weather forecasting and climatic information services are available, while in many developing countries, forecasts are either not accurate or unavailable altogether. Indeed, subseasonal or medium-range forecasts remain widely unavailable in developing countries, severely hampering farmers' ability to manage their farming activities in such a manner as to maximise their agricultural productivity. In Africa, for example, the existing market for commercial weather and climatic information services is extremely thin, with few private providers. A recent meta-analysis for West Africa suggested just a handful of commercial providers exist, despite 68 percent of farmers expressing demand for climate information services and the willingness to pay was estimated as $2.01 on average, for daily forecasts (Ouedraogo et al., 2022). The paucity of private providers reflects both the difficulty of connecting suppliers and users of the service and technical difficulties in supplying forecasts.

While in some geographies the technology required to generate such forecasts and to distribute them to farmers either already exists or will be relatively easy to adapt, in others (specifically, tropical Africa), new forecasting methods are likely to be required, since existing methods perform poorly. This is partly due to existing methods being optimised for different weather systems, and ones optimised for various African conditions will be different. It may also be due to the specific unpredictability of convection, the region's primary source of rain, which may limit the ability of any system of forecasting to meet accuracy benchmarks from other parts of the world. This needs to be considered when defining success and considering whether any plausible system is likely to meet minimum requirements to generate large-scale benefits.

Secondly, some way of calibrating new forecasting methods with observed weather data is required, and this is a particular problem in Africa. World Bank research suggests that "hydromet"[17] stations—that provide important observational (as opposed to predictive) information on rainfall and water levels for farmers—do not report accurate data, and budgets to maintain key infrastructure run short each year. Modernization and adequate maintenance of these systems could cost a huge amount—more than $1.5 billion. Improving predictive weather technology (including predictive modelling) in tropical Africa, where existing predictive technology performs uniquely poorly, will require either investments towards improving these stations or the use of alternative technologies (though at present not fully proven), such as remote sensing. That this has not already been done privately reflects the relatively low commercial value of these markets, a result of low individual purchasing power of farmers; difficulty in aggregating farmers to create a viable market; and the lack of well-resourced, centrally managed weather forecasting institutions, which are the ultimate source of observational data in most developed settings.[18]

The benefits of rectifying these problems are not fully understood. Rosenzweig & Udry (2019) suggest that correct seasonal forecasts increase profits by $0.49 for every millimetre increase in realised rain on average, but if the forecast is incorrect, then the rate of profits decreases by $0.39.[19] The authors suggest that, on average, correct forecasts of a good or bad year, defined as a 1.5 standard deviation variation in rainfall in either direction from the historical mean, increases profits by 11.5 percent. Given that there are 119.7 million farmers in India (2011 India census), an increase on profits by 11.5 percent across all farmers in India, would imply a total gain of $388 million[20] accruing to farmers, with little in the way of administrative costs of delivery. Other ex-ante assessments done mainly in Sub-Saharan Africa estimate an impact range from 0 percent to 24 percent increase in mean profits, with a median of 9.6 percent (Pandey, 2007; Sultan et al., 2010). Spillover benefits are also evident. In Ghana, where one method of providing improved forecasts was tested and evaluated, not only farmers who received the forecasts but also those living nearby used this information to change their behaviour, specifically, the timing of planting and applying chemicals for days when light rain was forecast. Additionally, given that accurate forecasts were already being produced,

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[17] Hydromet is also called weather, water, and climate services forecasting. Such systems report the weather, but also rising river levels, river gauge, and further water-related information.

[18] The actual services used by farmers are usually commercial, however, with a range of different providers and services available, including specialized agricultural and horticultural weather services from the UK Met Office. See https://www.metoffice.gov.uk/services/business-industry/agriculture.

[19] Seasonal forecasts are long-range. It is unclear whether medium- or long-range forecasts are most important for improving farmer outcomes.

[20] The calculation uses mean profits of the ICRISAT farmers in 2011 rupees as the base.

the cost of providing these forecasts to more farmers was very low. Overall, the results of this test suggest that forecasts were inexpensive and effective at changing farmer behaviour; however, they did not increase overall profits enough for any effect to be statistically distinguishable from zero, despite forecast accuracy above 80 percent (Fosu et al., 2018). This may be due in part because forecasts were relatively short term (two days), and farmers have a limited set of options in responding to information with so little notice. Also, the study was not large enough to detect small differences in profits. Longer-range forecasts may generate larger returns. The research to date on this problem has not been definitive about the optimal range for forecasts to improve farmer outcomes, the optimal format with which to provide the information, or the external validity of either, which may vary with location.

What's more, support for weather forecasting brings primarily adaptation benefits, without (known) large positive environmental or climate externalities. There are no studies we are aware of that test for any environmental impact of more accurate forecasting by farmers, though there may be some gains in the efficiency of resource use. Cost-effectiveness thus depends on achieving very low (marginal) costs, better evidence of the size and incidence of the benefits of forecasting, and how to maximise their welfare effects (through accuracy, presentation and use, and facilitating farmer action in response to them).

Designing a pull mechanism

The development of much better, more granular, and longer-term weather forecasts, with strong impacts on development outcomes thus requires the solution of several layers of problems. First is the necessity of better assessing the economic benefits of such forecasts to allow a better estimate of the optimal level of provision and willingness to pay for forecasts. Second is the need to investigate the format and method of distributing forecasts to incentivise their optimal use by farmers—which likely requires further innovation. Third is the need to resolve missing technological responses to specific problems in certain geographies, including both better modelling and construction of forecasts and better calibration by use of observational data either through more up-to-date and better-maintained existing technologies or through new technologies. Fourth is the need—if the previous three layers can be successfully resolved—to bring forecasts to the optimal scale (given low marginal cost, optimal scale likely to be very high, provided benefits are at least moderate).

A pull mechanism could be structured to resolve these problems. It could be structured so that a small initial phase generates evidence (ideally through an RCT) of net benefits in places where the technology is close to market, over a large and varied enough sample to motivate a decision on whether an expanded second stage is warranted. The second stage might involve a subsidy to 'top up' the farmers' actual willingness and ability to pay (which may be zero); since the marginal cost of the provision of forecasts is low, such a subsidy could dwindle to zero or near zero over time. It could essentially take on the transaction costs of reaching many atomised consumers from commercial providers, buying in bulk, and distributing forecasts themselves, experimenting iteratively and by location on the best way to package and distribute these forecasts.

It is likely that any such two-stage process may need to be repeated separately for closer and more distant technological solutions, especially since for some candidate locations there remains uncertainty about the possibility of sufficiently accurate technological solutions and the benefit to farmers of having them (and which formats for conveying information are best), even if possible. For more complex cases, evidence from places where existing systems are more reliable is less likely to generalise.

This does, however, raise questions about whether pull financing is the optimal approach for this application. At least some of the problems set out above can also be addressed by push financing considerably more simply. It is possible that a more efficient approach is to invest in multiple research studies that establish the welfare effects of different forecast ranges as well as the best ways of delivering information to farmers and facilitating their ability to act upon it before committing large-scale funding to bring the technology to scale, which could use a pull structure.

The costs involved are mainly manageable. Private weather forecasting providers are already close to being able to offer accurate weather forecasting to some underserved areas, though additional investments in forecasting models and adaptations are required—estimates from private providers suggest around $0.14 million for India or $1.2 million in the Democratic Republic of Congo would be sufficient. This suggests a structure under which a lump sum large enough to cover (some of) these costs and induce entry of multiple players is offered to any private provider able to meet specified performance benchmarks (accuracy, timeliness, format, and accessibility), with an annual bonus for reliability over time, and distribution to farmers undertaken by a third party for free (since the marginal cost of provision is near zero) could simultaneously encourage market entry and widespread take-up. Even if per-farmer benefits in terms of profits are low, a zero or near-zero price for forecasts could result in sufficient take-up to achieve cost-effectiveness. Such a structure would be closer to a prize than an AMC. Alternatively, to encourage ongoing competition, an annual, competitively renewable fee structure could be used and set to such a level that full R&D costs, plus some additional amount required to incentivise interest, are achieved over a couple of years if take-up is sufficiently high; this also creates an incentive to continually innovate to improve the product and compete for the market. However, this would be more costly; consequently, a pilot to pin down the size of the welfare benefits is recommended to better estimate the upper bound on benefits (and hence willingness to pay), with the actual prize value bounded by the estimated adaptation costs for the settings selected by funders.

In areas where accurate forecasts are not yet available, given the small marginal cost of each additional forecast, a pull mechanism should incentivise as close to full provision as possible. With a zero or near-zero price per forecast, the aim should be reaching all farmers who derive any benefit at all from better forecasting.

Contracting concerns appear relatively easily negotiated; forecast performance can be well specified, though, as noted, verification may be difficult in certain geographies in the absence of technological improvements in weather data collection. Usability is trickier, but the prize structure allows the possibility of awarding the prize to any provider that meets minimum forecast standards, based on a subjective assessment of usability made by an organisation tasked with distributing forecasts to farmers. This structure depends on finding the right partner, with experience working with farmers and being responsive to their needs. Per-farmer bonus payments will depend in part on the quality of the forecast technology and partly on the success of the partner in reaching farmers. This may create some contracting complications, which need to be further investigated, and may affect the optimal structure for any pull mechanism in this space.

Crop-residue burning

The case for intervention

Crop-residue burning, also known as stubble burning, is the practice of intentionally setting fire to the straw stubble that remains after grains, such as rice and wheat, have been harvested. The technique remains widespread, particularly (but not only) in Southeast Asia, in large part because it is an easy way of removing unwanted residue after harvest, clearing the fields for the next planting, and combating weeds and pests, while requiring little labour and almost no expensive technologies. However, the practice has extremely high local and global negative externalities.

In India, for example, where one million people die per year due to air pollution, an estimated 65,000 deaths are due to crop-residue burning. A recent study estimates the health burden of crop-residue burning at $1.529 billion over five years (Chakrabarti et al., 2019).[21] Beyond deaths, there is increasing evidence that air pollution brings large economic, cognitive, and broader health costs (Dechezleprêtre et al., 2020; Lvovsky, 1998; X. Zhang et al., 2018). These costs are purely local. Stubble burning also has a global cost in the form of emitted greenhouse gases. The burning of crop residue emits 211 million metric tonnes per year of carbon dioxide in India alone, which, costed at $51 per ton of carbon amounts to roughly $10.8 billion worth of carbon each year (Ravindra et al., 2019). Such a scale of emissions is globally significant; it would have accounted for 0.6 percent of total global emissions in 2019, and that just from stubble burning in India where the practice is best researched. It is also common in other parts of the world, including Africa, where the use of burning is often much more intensive than even in India (Cassou, 2018).

This makes a portable (in the sense that it works in multiple settings), scalable solution to burning one of the rare issues that holds promise both entirely on development grounds and on Global Public Good (GPG) grounds. The local development gains are also larger than the global public good benefits,

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[21] A corrigendum was issued on this paper, revising downwards the cost estimate from $152.9 billion to $1.529 billion (Chakrabarti et al., 2020).

which means that funding investments in a solution using ODA is logical. We consider three possible solutions at different distances from the market below.

Designing a pull mechanism

The first solution is the use of an existing mechanical alternative to crop-residue burning, the happy seeder. The happy seeder is an Indian technology that mulches and spreads stubble over the field, allowing direct sowing of the next crop, while the stubble's organic value is absorbed into the field. The productivity of fields sown using the happy seeder technology is, in theory, superior to or comparable with fields prepared using stubble burning (Sidhu et al., 2007). Though a good solution on paper, the happy seeder has run into several problems in practice. Firstly, the technology is very expensive, costing about 130,000 rupees each; even with a 50 percent subsidy and a loan, Pandey et al. (2020) suggest that most farmers will be unable to purchase one; sharing platforms are a possible solution, but they need to be able to respond to highly correlated patterns of demand (with farmers all needing to sow at around the same time); this means that sharing platforms may not be much cheaper than individual purchase or leasing. Secondly, the happy seeder is not entirely user friendly. Some farmers suggested that the yields were not as high as promised and relied on a great deal of learning.[22] And thirdly, some farmers argued that using the happy seeder increased the presence of pests; it had private costs that weighed more heavily on farmer decisions than the primarily external benefits it brings. A further problem is that crop residue burning in other countries does not always relate to paddy farming and the happy seeder may not be an appropriate technology in all cases, and it is unclear how well the happy seeder will work in such settings. A pull financing mechanism could be used to either incentivise take-up of the existing happy seeder technology (to the extent that a deeper subsidy or innovative marketing, machine sharing, or demonstration can increase take-up) or to incentivise the development of an alternative technology that avoids these problems. This could be costly, however. Even if a 50 percent subsidy was sufficient to induce take-up (and the evidence suggests it may not be enough), this amounts to around $1,700 per machine. In 2021, more than 70,000 crop fires were detected in India, almost certainly an underestimate given the difficulty of monitoring them. Even taking that conservative estimate would suggest a cost of around $120 million to encourage take-up of the happy seeder in India alone, a conservative lower bound on the cost.

A second possible solution is to take advantage of the fact that stubble burning is often already illegal or highly regulated but extremely difficult to adequately monitor. Improving monitoring of burning (detecting fires to enable penalties) allows governments to identify and fine transgressors and reduce the use of burning through disincentive effects. Technologies to undertake such monitoring already exist but are not deployed in India at present. Using high-resolution satellite imagery to detect fires at plot level could enable outcome-based rewards and penalties. While a pull financing mechanism could be designed to implement better monitoring, it is not clear how

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[22] See for example: https://indianexpress.com/article/explained/explained-using-happy-seeder-and-how-it-affects-wheat-yield-6017640/.

effective this would be in deterring stubble burning in practice. In particular, the gap is wide between the technology whose provision is to be incentivised (plot-level monitoring) and the outcome desired (cessation of stubble burning). The state needs to be able to collect, analyse, and act on the information, then demand and collect fines without providing legal or illegal forms of fine avoidance among farmers. And farmers need to respond to the (dis)incentive of the fine sufficiently to shift out of stubble burning. This complicates contracting. A payout on delivery of workable technology does not necessarily translate into action at scale against the underlying problem; but it is unlikely that a contract based on impact, which depends on so many other actors, will be attractive. What's more, the welfare effects of a system of fines are different to those of a system based on alternative technologies: fines reduce farmer welfare, especially in the presence of credit constraints that prevent them from using alternative technologies.

A third potential solution is the use of biological products (such as bio-enzymes) that decompose crop residues rather than mechanically extract them, both obviating the need for burning and enriching the soil (in theory). Such technologies already exist, though independent evaluations are not yet available. They have the advantage of not requiring mechanical tractors, but have, so far, typically been applied by teams of boom sprayers, free of charge to farmers. A pull financing mechanism could either reward a cheap, easily scaled way of dramatically increasing coverage through existing methods or the development of an alternative method of application that farmers can purchase and apply themselves. Since bio-enzymes both remove stubble and fertilise fields, much of the publicity around them suggests that they increase yields as well as obviate burning; a pull instrument rewarding take-up should be attractive to firms if such claims are true, as there should be a nonzero price at which they outperform burning. Such a price could be topped up by a pull mechanism to induce market entry and production scale. Over time, it could be scaled down as increased production and deployment capacity reduces the marginal cost of supplying one additional farm. If additional evidence of effectiveness is required, an initial demonstration prize could be offered for rigorous and independently evaluated field demonstrations that meet minimum technical standards, with the remainder of the payment linked to take-up.

With three potential approaches to scaling responses to stubble burning and no strong prior belief in which one will be most effective, responding to crop-residue burning is well-suited to a pull mechanism that specifies an upper limit on payment based on outcomes but no specific method of delivery of outcomes. While different technological responses to burning might require a different contract structure, it should be feasible to draw up a contract that delivers a prize for proof of concept (if for a new or adapted or unproven technology) with a scale for different classes of technology, and then a per-user subsidy, again with a scale for different classes of technology. Contracting will therefore be complicated, but possible. The metrics used for payout would be a combination of technical benchmarks (for a prize component) and a user purchase or use (to the extent this is monitorable—for example, if the purchase involves boom spraying, or renting machinery). The objective of the pull mechanism would be to either reduce the cost of existing solutions to increase use or the development and scale-up of a new technology.

Clean cooking

The case for intervention

A fourth candidate area for pull financing is clean cooking. The primary attraction of clean-cooking technologies is their development impact in the form of local health benefits—though some estimates of the climate impacts are substantial, with the problem concentrated in South Asia and East Africa (Bailis et al., 2015). More than three million people die prematurely each year from illnesses related to household air pollution associated with cooking according to the World Health Organization. Cleaner indoor cooking technologies can dramatically reduce such morbidity and mortality, by replacing solid-fuel cookstoves (which emit a great deal of carbon and have local air pollution effects) with either alternative energy sources or which are cleaner burning. However, the technologies developed to date have not achieved nearly enough scale in usage to realise the benefits available.[23] A pull financing mechanism that pays out on end-user take-up and use could incentivise greater efforts to design, produce, and distribute more usable cookstoves at an affordable cost. Some clean-cooking technologies are also associated with household energy access systems and mini-grid systems. It is possible to incentivise the rollout of each, thus creating local development gains on two fronts.

The local benefits of cleaner cooking technologies potentially come in two forms: more efficient energy use (and thus lower costs) and better health outcomes, while the GPG aspect comes from reduced use of high-emissions fuel, but not all technologies deliver all benefits in equal measure. Even switching to a more efficient solid-fuel stove, without completely substituting out the use of coal can reduce spending on charcoal by 40 percent, saving $118 per year on average per household. The associated reduction in carbon emissions would be around $146 per year per household (Berkouwer et al., 2021). Cooking technologies that eliminate the use of solid fuel can have larger benefits on household health and larger reductions in emissions but higher energy costs than existing systems. The direct costs of the system will be higher, even if there are still net benefits once potential health outcomes and expenditures are accounted for (Gould & Urpelainen 2018; Schlag & Zuzarte 2008). The benefits on health, however, should not be taken for granted. Measured impacts on health have been disappointing, though one possible reason for this is that take-up needs to be community-wide before health benefits are visible at the household level (a household using cleaner cooking surrounded by those using old technologies is unlikely to significantly improve the quality of air and therefore unlikely to reap large health benefits). Contracting structures that reward community-level take-up may be more attractive than those that function at the household level. Mechanisms like those used for microcredit interventions (where benefits to individuals are tied to the behaviour of their peers) may be worth investigating.

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[23] As of 2020, 2.8 billion people still cook with some form of biomass globally.

Designing a pull mechanism

For the most part, appropriate technologies already exist, but pull financing can be used to extend take-up of existing technologies by driving down cost and by incentivising continued (marginal) innovation that improves the usability and attractiveness of the new stoves (with the ultimate aim of accelerating uptake). Through many pilots, clean-cooking technologies have shown mixed results but illuminated many of the reasons why cookstoves have failed to generate the benefits expected. In many cases, households failed to use the new stoves regularly or appropriately, did not make the necessary investments to maintain them properly, and usage rates ultimately declined over time (Hanna et al., 2012; Lindgren, 2020). These randomized evaluations found that people did not use it because it was not adapted to their cooking habits or required a lot of maintenance (Lindgren, 2020).

Pull financing could be structured in multiple ways, primarily aimed at either reducing the cost of existing cookstoves or incentivising marginal improvements to usability to induce higher take-up and use. An AMC could focus on improvements to existing machines to make them better suited to consumer needs[24] by rewarding take-up, possibly at the community or neighbourhood level; or the development of cheaper alternatives among those that are currently best suited. Alternatively, a pull mechanism that focuses on aggregating consumers or distributors for bulk purchase, thereby reducing financial risks associated with large-scale procurement and driving down prices, can help scale quality-assured electric cookstoves solutions. A more ambitious—and risky—approach would be an integrated finance mechanism combining procurement subsidies, consumer financing, and access to carbon markets to make electric stoves more attractive. The ambition comes from the range and type of financing this seeks to access, to make clean cooking not just competitive but attractive relative to solid-fuel stoves. With the risk from the possibility that without technical innovation to increase usability and attractiveness on convenience grounds, take-up may remain low.

Scaling more efficient solid-fuel stoves may also benefit from some form of pull financing, though less attractive on climate grounds: there remains a substantial gap between the retail price of $40 of the most effective and usable models and the willingness to pay of consumers at $12 (Berkouwer et al., 2021). Any mechanism that seeks to incentivise take-up can either pay the full $28 subsidy, seek to expand production to reduce the per-unit cost and reduce the level of subsidy required, or establish a new payment structure that takes advantage of fuel savings.[25] A zero-interest loan or rent-to-buy agreement could be a cheaper way of stimulating take-up, though it should be noted that Berkouwer and co-authors (2021) found that loans increased willingness to pay without entirely bridging the gap to retail price; a subsidy would still likely be required, at least initially. Achieving scale in take-up and scale economies for any clean-cooking technology in production is plausible, given the vast market size. Depending on what technologies households already use, different

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[24] This includes the technology itself, its suitability to the context, including the sources of energy widely available, and the price

[25] Or a combination of the first and second, with the subsidy tapering off as the cost of production declines with installed capacity and increased efficiency in production.

clean(er) cooking solutions will be appropriate, but a substantial proportion of these households will—in theory—form the market for each type of clean-cooking intervention. Take-up depends on the relative attractiveness of cleaner technologies and existing solutions, on up-front price, running costs, usability and convenience, and on private benefits such as cleaner household air, to the extent these are internalised in household decisions.[26]

Assume that a $28 subsidy provides one way of estimating the upper bound of the cost of such a mechanism.[27] If a similar subsidy is required for cleaner alternatives, and the aim is to accelerate uptake in at least one-quarter of households for whom local, indoor pollution is a serious problem, providing the full subsidy to even ten million households would cost $280 million. Though this is still a good investment on economic grounds (since benefits are much higher than this per-unit cost), this may be more than what most donors are willing to commit, given that in 2019, OECD DAC donors provided just $0.815 million in total for cleaner cooking appliances.[28] An alternative structure could be a staggered pricing schedule designed to incentivise investment in production and rollout capacity to drive down the cost of production and retail for these cooking appliances. Such a structure could provide, for example, a more-than-$28 subsidy for the first five or ten million stoves produced, dropping progressively for each additional five million stoves produced (conditional on some large total number of stoves produced and some verification of use). The intent would be to induce early and rapid entry of producers into the market, with production capacity installed at large scale early, thus increasing supply and driving down production costs and prices early to allow for a rapid reduction in the level of subsidy provided while maintaining profitability for private producers. The exact subsidy structure would depend on detailed market analysis, but such a system would be substantially less costly than maintaining a full subsidy indefinitely, even with a lower initial subsidy level. It would also incentivise producers to innovate and roll out quickly, to take advantage of the higher subsidy level. Combining either structure with a zero-interest loan or rent-to-buy purchase structure could reduce the cost further. To aid in setting the initial subsidy level, a reverse auction could also be held, with the number of units to be purchased set in advance.[29] This has the benefit of using the market to identify the smallest subsidy required but works best when price (in this case subsidy) is the only dimension on which producers compete. Where product quality is multidimensional, there is the risk that producers emphasise small differences in design to generate

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[26] In theory this may not be the case if, for example, the purchase decisions are made by household members who do not bear any of the direct health burden.

[27] Since using a loan or rent-to-buy mechanism can reduce the cost of the subsidy below this level, at least for the cookstove tested by Berkouwer et al. (2021).

[28] The total amount committed under the OECD purpose code corresponding to "clean cooking and appliances" in 2019 is $0.815 million to data from the OECD-DAC Creditor Reporting System.

[29] Some risk-sharing structure may need to be agreed upon for this to work, though the majority of risk should fall on producers making subsidy bid.

some level of market power; in such a case (effectively monopolistic competition), the equilibrium of a sealed-bid auction will not necessarily be to discover the lowest subsidy required.[30]

Contracting for such a structure has two problems. First, the decision of at what level to set the subsidy, both initially and as production increases, requires some level of market and production knowledge. This is not insurmountable, but poses a problem, since funders cannot simply rely on innovator and producer self-reporting, and reverse bidding under conditions of product variation and monopolistic competition is unlikely to discover marginal costs (see footnote 32). The second problem is a contracting decision related to whether to pay for production, purchase, or use of the cookstoves and whether this should be at household or community level. Contracting on community-level use gets closest to the impacts desired but is hardest to verify; contracting on production is simple to verify but quite a distance from final impact and difficult to justify, even if restricted to cookstoves that are produced at a (subsidised) price known to be attractive to end users. Contracting on purchase is easier than on use but does leave the possibility that stoves are sold and not used consistently. Since ideal contracting arrangements are not possible, a pilot study establishing the relationship between purchase and use (at different prices) may be necessary before scale-up.

Cooling systems

The case for intervention

The demand for electricity to power stationary mechanical cooling systems is widely expected to more than triple between 2016 and 2050,[31] perpetuated by a vicious cycle between climate change and electricity demand for cooling. As the frequency and severity of heat waves increases, the demand for cooling equipment that accelerates global warming both through electricity demand (which, of course, depends on the source of electricity) and the use of hydrofluorocarbons (HFCs) in turn increases. The development of cleaner cooling systems that are more energy efficient represents one way of weakening or breaking this cycle; the same is true of heating systems, given the high burden of deaths from cold in many places (Cohen & Dechezleprêtre, 2020). This section focuses solely on the development and deployment of better mechanical cooling systems; nonmechanical cooling mechanisms are an important part of cooling in both developed and developing countries but are not discussed here.

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[30] A classical sealed-bid auction with a perfectly specified product and perfect competition among producers will result in an optimal bid for each producer of p=MC, that is, the marginal cost of production (including such a level of 'normal' profit that is required to induce entrepreneurial effort), below which any price would cause producers to make a loss. But if producers are able to create subtly differentiated products—perhaps with slightly different design features or different bundles of benefits—and a procuring agent which is unable to assess them with total accuracy against a well-specified set of requirements (since writing a complete product specification is very difficult indeed), producers are able to bid prices above marginal cost. This would mean that the mechanism does not discover the lowest subsidy required to move the market, but a higher one, and is very likely the set-up in the clean cooking space. This does not mean this approach has no merit, but simply that price discovery is imperfect.

[31] Data was retrieved from the report "The Future of Cooling" from the International Energy Agency.

The development gains of extending, expanding, and improving cooling systems are broad. Cooling systems are not simply a middle-income country problem, not only a well-being issue in the face of heatwaves but also an issue of food security, distribution, vaccine distribution, and value chains. Refrigerators and refrigeration systems are required for food and vaccine storage and movement. Where cooling systems are already in place, they tend to be inefficient and prone to breakdowns or outages. Where they do not currently exist, their use is both a direct utility benefit and effects on productivity and health outcomes (Somanathan et al., 2021; Sutton-Klein et al., 2021; P. Zhang et al., 2018). To be clear, food storage and vaccine distribution are logistical, policy, and political problems as well as technical problems, but there is a technical component to their solution. Better, more efficient cooling solutions represent an improvement at the margin where inferior systems currently exist and a more substantial welfare gain where no such system currently exists. These gains can be achieved in public settings (such as hospitals, schools, storage facilities) and private settings (factories and other places of business, homes). Their local welfare benefits, however, are difficult to calculate precisely since they depend very much on the existence and quality of systems.

There are multiple climate benefits to the use of more sustainable cooling systems (though the use of different construction materials and building houses with better cooling properties are an adaptive response to higher temperatures though without the same mitigation benefits, except insofar as they displace the use of mechanical cooling). At present, refrigeration uses HFCs intensively due to their safety, efficiency, and affordability. However, HFCs have very high global warming potential. The development of air conditioning systems that use alternatives to HFCs and are more energy efficient than typical current models has the potential to materially shift climate outcomes. This is true even based on simply upgrading existing systems, since mass cooling in public settings is already a large source of greenhouse gases, even in developing countries. The cooling systems used in hospitals alone in Africa accounted for around 30 million metric tonnes of carbon dioxide in 2018. Considering the expected increase in demand for cooling in places where it remains underprovided over the coming decades, the effect will be even larger. Using a conservative social cost of carbon, making even a small dent in these emissions would have returns far in excess of what could reasonably be spent on cooling. This, too, represents an extremely conservative lower bound on the maximum achievable scale for better cooling solutions, being just one application in one setting. The full range of public and private applications is likely much, much larger.

Designing a pull mechanism

The fact that private uses of cooling are likely to be as extensive or more extensive than public uses over the coming years in developing countries makes the case for a pull mechanism more compelling. At present, energy-efficient, non-HFC cooling systems exist and are widely adopted in developed countries, though improved technologies would still be beneficial. Estimates suggest that better technologies have the potential to reduce electricity consumption by 38 percent and eliminate 400,000 kilograms of carbon dioxide emissions (Anderson et al., 2021; Gao et al., 2019).

However, at present, the best-in-class technologies are substantially more expensive than the market average in most developing countries—making some mechanisms to drive down prices attractive.[32] Several pull mechanisms could help resolve this issue, and a forthcoming note (Stephens et al., forthcoming) goes into much more detail on this, making the case for an AMC to stimulate both innovation and the instalment of production capacity for residential cooling only, estimating a cost of $196 million to $373 million. Full details, including verification metrics and contracting structures, are discussed in that note. Other mechanisms are also possible. One very simple structure would essentially create (and subsidise) a buyers club, potentially structured over time to induce market entry; investment in production capacity and increased supply could be used to both induce further technological innovation and drive down the price of existing technologies. Such a buyers club could be structured around public facilities such as public hospitals and medical and food storage systems but would have the spillover benefit of reducing prices for better, cleaner cooling systems for private purchasers as well. It has the advantage of simplicity (essentially reducing to a coordination problem, potentially with a subsidy element) and lower cost but runs the risk of securing benefits only from bulk purchase, rather than incentivising the instalment of additional production capacity and innovation—especially since each club needs to be small enough to aggregate only those buyers who want to purchase the same thing.

Buyers clubs can be structured in different ways, and at different costs. One option is to simply aggregate purchasers into a sufficient quantity that enables bulk purchase and/or market entry under specific conditions, with no subsidy at all. Such a buyers club could be financed for the cost of outreach, communication, and some contracting capability, in all likely to be in the region of $1 million.[33] An alternative would be to subsidise the purchase of higher-quality, cleaner units (using some prespecified criteria) to increase or bring forward demand.[34] If technologies meeting these criteria already exist, this would encourage investment in production capacity; if not, it would incentivise innovation, provided the purchase price was sufficiently high—at the limit, this kind of approach amounts to an AMC, and the forthcoming working by Stephens et al. sets out the requirements and details for delivery carefully. This would be substantially more expensive, depending on the level of the subsidy but also more flexible and likely a more effective system.

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[32] This is a well-known problem. The Global Cooling Prize included reductions in cost as one of its criteria for funding. See https://globalcoolingprize.org/.

[33] A buyers club on these terms in the healthcare sector in Brazil was structured for the cost of around $400,000; an international club would have higher variable costs of outreach, but certain fixed costs would not vary. In a pilot in Brazil, it was calculated that replacing all of the refrigeration in 33 hospitals would require around $6 million in investment in total. The estimates of the cost of the Brazil example are taken from a presentation by Dr. Gabrielle Dreyfus, Dr. Stephen Anderson, and Dr. Suely Carvalho on 8 September 2021 during a private roundtable at the Center for Global Development and a webinar by Dr. Suely Carvalho and Vital Ribeiro entitled "Towards economically sustainable EOL schemes: A case study from Brazil." Further details of the buyers club (but not the cost data) are available at http://www.igsd.org/wp-content/uploads/2020/07/Buyers-Club-Handbook-Jan2020.pdf.

[34] Such a system would require narrowing the mechanism to focus on technologies with a sufficiently high level of standardisation.

Given that most cooling operates as installed capacity, and the main characteristics of better technologies (increased energy efficiency and the absence of HFCs) should not substantially vary over the life of the installed units, contracting metrics are fairly straightforward. If the pull mechanism specifies energy efficiency requirements, these can be lab-tested; if it pays out based on uptake, it can be measured in terms of installed capacity or purchased units. This makes cooling one of the more attractive, lower-risk pull financing applications available.

The next two potential applications we discuss require further scoping but show sufficient promise to warrant such further investigation.

Green, all-weather road sealants

The case for intervention

Africa's unmet infrastructure needs are enormous, and high-quality, all-weather roads form a substantial component of this shortfall; Africa has 31 kilometres of paved road per 100 square kilometres of land, compared to the low-income country average of 134km (Holtz & Heitzig, 2021). Road-building programmes are consequently extensive. The World Bank's total commitment on road building was larger than to education, health, and social services combined (Freeman, 2007). "In fiscal year 2013, the World Bank's total transport commitments amounted to 5.9$billion, and rural and interurban roads remained the largest subsector, accounting for 60 percent of total lending" (Ali et al., 2015; World Bank, 2014), and more was spent through bilateral aid, the Belt and Road Initiative, and domestic revenues.

The road sealants most commonly used—concrete and hot mix asphalt (HMA)—are both highly carbon intensive (see, for example, Espinoza et al., 2019) Developing an affordable, greener alternative could have an appreciable impact on global emissions, given the scale of road building and maintenance required to close the infrastructure gap. Some alternative technologies (such as geotechnical mats or soil stabilizers that increase the load-bearing capacity of unsealed roads) already exist but are either prohibitively expensive or have failed when tested in real-world settings. A pull mechanism designed to induce innovation in either better technologies, greener methods of producing HMA, or cheaper alternatives to existing green technologies could have substantial climate returns.[35]

Estimates vary regarding the development return to improving transport infrastructure. Donaldson (2018) provides a positive estimate based on railroads in India; Asher & Novosad (2020) have a low estimate based on road resurfacing in very rural areas of India; and AfDB (2014) estimates a much higher—but less well-identified—development impact. At the very low end of these estimates, better

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[35] A similar case could be made for supporting greener cement or other construction materials for infrastructure, especially solving developing country specific problems, like inefficient on-site mixing, which results in less durable and higher-carbon infrastructure.

road surfacing would provide relatively little in the way of development impact, but it should be noted that these lowest estimates are for the most rural areas; much of the road surfacing requirements in Africa remain in more urban areas, with greater importance for trade and the movement of people. None of these estimates include effects on road safety, a substantial development issue in Africa in particular, though road quality itself is only one of several contributing factors to the high mortality and morbidity burden of road accidents.[36] The low-end estimates of development impact should, nevertheless, have some influence on funders' willingness to pay for new technologies.

Designing a pull mechanism

A pull mechanism could work in one of two ways. One possibility is the deployment of a prize dependent on specific cost and performance characteristics. Cost would need to be competitive with existing road sealant methods, and a high-stress, real-world performance test (for example, survival through monsoon rains) would need to be passed before the full prize is released. Prize challenge experts suggest that a prize in the region of $25 million could be sufficient to induce innovation directed to African conditions, given that private firms are already working in this space for private clients.[37] An alternative mechanism would be using large procurement guarantees through the World Bank or other donors: if a road technology meets cost and technical standards and passes a real-world pilot, such purchasers could commit to using the technology for up to, say, 50 percent of the roads they finance. This would also incentivise production scale-up to take advantage of the purchase guarantee.

That said, alternative, high-performing road sealants remain a higher-risk application. The technical specifications and distance to market of appropriate technologies are less clear, and the development impact is more variable depending on where it is applied. It is perhaps better suited as part of a portfolio approach or a moonshot project. Alternatively, an initial push-funded exploratory phase could be used to further develop the case for pull financing and its technical, monitoring, and contracting requirements.

Electric vehicles for Africa

This is the application we cover that needs the greatest amount of further development. Electric vehicles are expected to form an increasing proportion of the vehicle stock in Africa in the future, as production of conventional vehicles slows and countries (such as Kenya) take steps to end the importation of used conventional vehicles. However, the uptake of electric vehicles in Africa faces specific local problems for which a pull financing mechanism may provide part of the solution. These are:

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[36] See https://www.afro.who.int/health-topics/road-safety

[37] This is estimate is drawn from personal communication with organisations involved in prize setting for innovation. Further work is needed to verify its accuracy.

- **Last-mile adaptations to the vehicles themselves:** Electric vehicles so far developed have been designed for different terrain and usage patterns than those that exist in Africa. Adaptations could be made a range of vehicle types in private or public operation such as heavy-duty vehicles, buses, minibuses for public transport, two- or three-wheelers, and so on.
- **Charging infrastructure:** Though potentially profitable, the charging infrastructure for electric vehicles is severely underdeveloped. Battery-swapping stations are an alternative.
- **High prices for electric heavy-duty vehicles:** The high prices for electric heavy-duty vehicles suggest a role for a pull financing mechanism to drive costs (and price) down.
- **Purchase incentives:** Against competition from second-hand vehicles, a larger subsidy may be required to build the market rapidly and thus exert pull pressure on the first two problems.

Pull financing to reduce the cost of new vehicles or stimulate entry into the market for charging points could play a role in accelerating the rollout of electric vehicles in Africa, especially given how dramatically underfunded the rollout of zero-emissions vehicles is. The climate implications of such a change are large (though they depend, of course, on the energy generation mix in use), but the development benefits are less so: they depend on the marginal improvement of moving from petrol to electric vehicles. These could come in the form of lower running costs, local pollution benefits, and associated health returns; however, these need further investigation. The exact form of a pull mechanism is also unclear; while push financing seems inappropriate for the rollout of electric vehicles, it is not obvious that it would not be a simpler and more effective method to induce last-mile adaptation or entry into the charging infrastructure market.

Constructing a Portfolio

The foregoing analysis suggests that several highly promising applications that pull financing for climate and development outcomes can be applied, and though detailed contracting and costing work are still required for the final applications selected, a broad ballpark figure for many can be constructed. Three challenges remain: deepening and widening the range of applications; defining how a portfolio of applications should be selected, including consideration of the relative impact of different potential applications; and finding the right institutional setup for managing the mechanism. We discussed the process for widening the pool of potential applications earlier in the note. We turn now to how a portfolio should be constructed.

A portfolio of pull financing applications should seek to balance the following characteristics:

- **Relative impact:** The applications set out here are widely varied, and any additional potential applications sourced can only be expected to further broaden the range of issues considered. This creates a problem for policymakers: comparing the expected utility from pursuing different applications when there are few common metrics for success. Despite this, such judgments are critical. Of the applications considered in this note, solutions for clean crop-residue burning and better, more resilient seeds and crops are likely to have substantially larger benefits than most of the other applications covered—though the likelihood of success and contracting difficulty (as well as the size of the pull mechanism required) varies across applications, a portfolio that pursues at least some potentially massive gains is more attractive than one that focuses on smaller problems, even if they are more tractable.

- **Cost:** The applications set out here range from highly expensive (subsidising the happy seeder or subsidising the rollout of clean-cooking technologies) to potentially cheap (weather forecasting adaptations to new markets).
- **Speed/distance to market:** Some of the applications suggested are likely to be quick to generate innovation and returns, such as improved weather forecasting, while others may have a lead time of several years before an appropriate technology or critical mass of take-up is achieved. A pull facility that seeks to have relatively smooth payouts and returns over time would need to carefully select a mix.
- **Risk:** This is closely related to distance to market. Some big-ticket applications—specifically combating stubble burning and the development of better seed varieties—are riskier than others. The risk can come on the innovation side (it is not clear that an effective technology can be developed to obviate stubble burning in places where monitoring is imperfect), or on the contracting side (the risks of contracting for seed development are greater than for most other applications, given the difficulty of specifying the correct bundle of attributes desired for any given seed, and the difficulty of monitoring seed use, as opposed to one-off purchases). A portfolio that consists partly of of high risk, high return investments together with more steady bets is likely to be most attractive to donors, even if the expected value of a portfolio focuses on the riskiest, biggest bets is likely to be highest.
- **Development versus climate benefits:** The balance between development and climate (mitigation) benefits across these technologies varies widely. Some have large benefits on both grounds—most notably stubble burning, which makes it one of the most attractive applications here and a potential centrepiece of such a facility. A facility that, on aggregate, aims to have large gains on both development and mitigation fronts needs to select its portfolio carefully.
- **Location of benefits:** Some applications are more applicable to poorer countries, while others are likely to deliver larger benefits in relatively richer, developing countries. A pull facility for weather forecasting, for example, is likely to be most suited to poorer countries, where providers have the weakest market incentive to provide services, while cooling systems are likely to have the largest benefits in middle-income countries in which cooling systems are more widespread already and being installed in greater numbers. A portfolio balanced by location will also return a range of development and climate benefits.

There is not a clear upper limit for how large a pull facility structured around these applications can be. Forthcoming work will look more deeply into the contracting requirements for two of the applications considered here (crop-residue burning and clean cooling) and will provide greater insight into the financing requirements for these applications. But particularly, if a pull financing institution looks beyond development applications, the upper limit on scale is likely to be measured in billions, rather than millions of dollars. Furthermore, even if limited to development applications, for which some aid can be used, there is no obvious upper limit on size—for example, developing and scaling better seed varieties for multiple crops in multiple iterations. The more funders are engaged and the higher their ambitions, the more a pull facility can achieve. The bigger the fund across a broad range of applications, the more private sector interest and effort will crowd in and the larger the likely development and climate benefits; the returns to scale of ambition are likely to increase. The remaining questions to settle, then, are the institutional structure best suited for managing and implementing such a fund and the fine details of contracting for any applications chosen.

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