Economies of Scale in the Production of Cannabis
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Introduction

Economies of scale is a term used to describe decreasing average cost of production (for example, the cost of producing a pound of cannabis) as a grower's total output increases. Economies of scale prevail if unit costs fall as output increases (if the elasticity of costs with respect to grower's output is less than one). Economies of scale might be realized either if there are diminishing marginal costs or if there are fixed costs of production (fixed costs such as capital equipment and plant construction are spread over a larger scale of output). Economies of scale might also result from improvements in organizational structure, productivity gains from labor specialization (with a higher output, workers can specialize more narrowly on specific tasks that they may better perform than if they devoted only a small share of their time to that task), and technology improvements. Members of the BOTEC team interviewed High Intensity Drug Trafficking Areas (HIDTA) staff in June. These discussions revealed that organized crime groups are running networks of houses and overseeing high-quality operations in terms of lighting, ballasts, layout, etc.[2] The organized crime groups are hiring professional electricians, professional carpenters, and more generally specialist labor at each step, as compared with the medical access point's providers who appear less sophisticated by comparison, with many doing their own construction and design (the consequence being a less sophisticated set up). We anticipate that I-502 will provide some external economies. Even today's small producers might be able to hire the sort of professionals currently employed by the organized crime groups, if only they are able to advertise and freely seek out that sort of professional help.

This paper focuses on *internal* economies of scale (the change in costs a grower would experience because of an increase in his output). Cannabis growers may also benefit from *external* economies of scale, in which increases in the output of an entire industry produce marginal cost savings for the entire industry, decreasing the average costs of production for many firms all at once. External economies of scale exist if growers benefit from being close to other growers. These may take the form of labor pooling, sharing common assets, better availability of intermediate inputs, and sharing know-how. An important external effect for growers might be shared enforcement risk (federal enforcement is more difficult as the number of growers increases). For some external economies of scale, it does not matter whether growers can communicate (e.g., for enforcement swamping) but for other external economies, what may matter is not only the total number of growers in the area, but also the ability of those growers to trade information, expertise, share suppliers, etc. We do not model external economies of scale,

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[2] There are Mexican gangs, for example, who are large outdoor producers, and do not fit this description. Production economies are quite different for indoor compared with outdoor growing. In this paper our interest is focused on indoor and greenhouse growing.

but we provide some comment regarding the implications of external economies in our review of licensing options.

Why would regulators of legal cannabis production be concerned with economies of scale?

If economies of scale are present, estimating the magnitude of the scale effects is important for informing decisions regarding the optimal number of licenses to issue. If the economies of scale are very large, and persist indefinitely for larger and larger operating scales, then growers producing at a large scale might exclude small-scale farmers from successfully competing. Economies of scale therefore have implications for the number (and size) of growers that would be feasible in an unregulated market. This has implications for costs, price, product variety, and regulatory burden. Strong economies of scale would favor large growers, an oligopolistic market structure, and concentrated production; accordingly, they may strengthen the arguments for policies intended to mitigate those outcomes. Another reason to pay attention to economies of scale is that they affect the severity of an expected legalization-induced price decline, which in turn affects regulators' ability to drive the black market out of business as well as combat likely associated increases in use and abuse.

Description of project and goals

This paper examines the cost curves of cannabis production for indoor and greenhouse cultivation. Our particular focus is on assessing the size of economies of scale: does the average cost of production drop significantly as the producer becomes larger? An ideal analysis would involve observing organizations at multiple different operating sizes. This sort of data is not available. Instead, we observe separate costs for growers of different sizes and infer that the cost curve is the line that passes through these points. This approach is suboptimal but it is the best currently available way to estimate cost curves.

Drawing on data from previously published work and unpublished estimates from confidential sources, we generate cost curves for cannabis production that show how costs vary with scale. We also describe data from a new marijuana producer survey, and provide a summary of lessons learned from the 186 marijuana growers that were surveyed.

We then assess the impact of an increase in production volume (i.e., how much would costs fall if production shifts to larger producers) and provide estimates of the minimum efficient scale (the production quantity for which average cost is the lowest).

Finally, we assess industry costs under various licensing schemes (e.g., mandating a particular number of small producers), with the intent of determining if there is a minimum viable size for a producer.

Review of previous work on estimation of costs for growing cannabis

The literature on the costs of growing cannabis can be grouped into three categories: cost estimates produced by advocates, industry promotion groups, or "how to grow" writers; unpublished or non-peer reviewed work that is nevertheless of academic quality; and peer-reviewed academic studies. Here we focus on examples of such work that we examined. This section is not meant to be an exhaustive review of the literature on the costs of producing cannabis. Instead, we combed through all the previous work we could find that were relevant for estimating economies of scale, and report those findings here. We also looked at work from the field of agricultural economics that, while not specific to cannabis production, concerned closely related crops and was therefore considered relevant for our discussion of economies of scale. We close this section with implications of the findings for our work.

Literature regarding cannabis production

Given the practical difficulties involved with conducting primary research on a largely illicit industry, much of the best-known and most heavily relied upon cost work is in the first two categories mentioned above. Our study relies heavily on the work of Caulkins (2010) and Denman and Cooley (2013) in particular, and we review those first.

Caulkins (2010)

Caulkins (2010) estimates production costs for legalized cannabis in three scenarios: a small and medium indoor growing operation, greenhouse growing, and outdoor farming in a "gray market" context (meaning no risk of arrest but nevertheless a requirement to remain subtle) and after enough time has passed for some technological innovation to have occurred (e.g., modest mechanization of trimming). While the report is not peer reviewed, it is one of the most highly cited papers in this area of research, and work relying on it in part has been published in peer-reviewed academic outlets (Caulkins *et al.*, 2011; Caulkins and Bond, 2012).

The main finding of Caulkins (2010) is that legalization may be expected to lower the wholesale price of cannabis dramatically in the long run, compared to then-current prices for the illicit product. This conclusion is based on two observations stemming from the calculations in the paper. First, even when considering the costs of growing cannabis in

an inefficiently small indoor setting, the wholesale price for the illicit product is much higher than the apparent costs. Thus, either the production side of the industry enjoys a high degree of market power (monopolization) or there is a huge risk premium attached to the production process[3] (e.g., current growers pay even low skilled workers much more than is usual for farm workers, whereas Caulkins et al. presume the prevailing wage for farm workers would pertain). Given the apparently wide extent of illicit growing within and outside the US (see, e.g. Bouchard, 2008; UNODC, 2012),[4] the latter appears to be the more likely cause. To the extent that legalization at the state level reduces the risk of prosecution and seizure for producers of cannabis, this risk premium is expected to fall.

The second argument made in Caulkins (2010) for the expected decline in wholesale prices is based on production efficiency. The illegality of cannabis causes growers to make decisions about production aimed at minimizing risk rather than optimizing the production process based purely on agricultural and technical considerations. That is, an illicit industry will be structurally different than an above-board industry, with smaller growers than rationalization of production would otherwise demand.[5] Caulkins (2010) estimates that the cost per pound of cannabis produced is $225 for indoor micro-growing (with unpriced labor), $200-400 for a smaller indoor operation, $70-$215 for greenhouse growing, and less than $10 for large scale outdoor growing by professional farmers with modern farm machinery. While the quality of the product may not be the same across these scenarios, it is clear that if industry were to shift toward outdoor or even greenhouse growing that production costs would decline—perhaps dramatically—from current levels.

Caulkins (2010) speculates that economies of scale may exist in a few areas of the production process. Larger operations purchase materials in larger quantities, which may lead to quantity discounts from suppliers (p.4).[6] Larger operational scale also spreads out

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[3] See Caulkins *et al*. (2012, pp.37-38), for a brief, nontechnical discussion of the risk premium for producing cannabis.

[4] Production statistics for cannabis are understandably imprecise and subject to controversy in the field. However, as the following quotation from UNODC (2012) puts it, "[a]lthough estimates of the actual magnitude of cannabis production in the United States are lacking, eradication data point to continuing extensive cannabis cultivation in the country" [p.51].

[5] In the jargon of industrial organization economics, "rationalizing" an industry means adopting the industry structure that minimizes production cost. In many (but not all) industries, particularly those with heavy capital requirements leading to strong economies of scale, this means centering production in a few large firms (a tendency toward oligopoly).

[6] Note, however, that if such discounts were significant, we would expect that the industry (or a middle layer of purchasing agents) would organize collective purchasing.

fixed set-up costs over more units of production, lowering average cost (p.4).[7] Finally, he notes that legalization may spur process innovation and increased automation into the production process (p.2).

Denman and Cooley (2013)

The most detailed cost estimation for production of cannabis is the work of Denman and Cooley (2013) (hereafter, "the Solstice report"). The Solstice report estimates the production cost for two indoor growing operations and one outdoor scenario. Their estimates, particularly for the indoor scenarios, are based on actual operations at facilities associated with Solstice. Many of their costs, such as the cost of obtaining building permits, are specific to the Seattle area. Instead of summarizing all of their work here, we will explain which of their assumptions and costs we use below in section V.B.

The Solstice report suggests the potential for economies of scale to be realized in a few parts of the production process. The authors mention that there are volume discounts for electricity for larger customers. They also suggest that equipment prices are lower for larger purchasers, although they mention discounts of only 2-5% (without specifying what scales of operation are being assumed in this regard or what thresholds would trigger the discounts).

Other academic studies

Bouchard (2008) derives a methodology to estimate total illicit production based on evidence from drug seizures and arrests for production of an illicit substance. The part of this work of interest to us is the regression estimates of the number of co-offenders per cannabis plant seized and how this figure varies with the type of operation. The results show that for each of the three cannabis growing modalities considered, indoor, hydroponic, and outdoor, a minimum of three individuals are involved on average. More interesting for the economies of scale issue is how the number of co-offenders varies with the number of plants seized. In a very crude way, this measure approximates the amount of labor required per unit of production (including trimmers' time, which under current conditions constitutes roughly 50% of total labor time, and is not subject to economies of scale because it is trimmed by hand).[8] For every additional 100 plants, outdoor growing

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[7] As we show below, this notion assumes either a short-run view of cost or a belief in strong economies of scale in long-run variable cost. For our analysis we adopt the long-run view and do not find evidence of strong economies of scale.

[8] Caulkins' projections assume that with legalization, someone would figure out a less labor-intensive way to trim. Interviews with growers suggest they lack confidence that this sort of technology is likely in the near term.

is associated with 1.16 extra co-offenders, versus figures of 0.82 for indoor growing and 0.57 for hydroponic setups. Each of these estimates is statistically significant at the 5% level. If these figures were taken to apply exactly to labor productivity, they would indicate that there are economies of scale in the labor component of production.[9] However, since actual labor hours is not likely to be proportional to the number of co-offenders estimated from the statistical model, we do not build this assumption into our cost model.[10]

The findings also suggest that legalization may shift production methods away from hydroponic methods. The logic is as follows. First, legalization of cannabis production and the normalization of working in the field (in both senses of the term) may cause wages to fall (Caulkins, 2010, p.5). Then, as labor becomes relatively cheaper compared to equipment and materials, more labor-intensive methods of production become relatively more cost efficient. Per the regression results above, that means a shift away from hydroponics toward soil-based indoor growing. Countering this effect of legalization on lower wages, however, may be the additional costs of labor that would come to bear on a legitimate operation (payroll taxes, contributions to workers' compensation insurance, government-mandated healthcare costs, etc.).

A number of cautions are warranted regarding application of Bouchard's (2008) findings for present purposes. The data were from Eastern Canada, not the Pacific Northwest. Counting co-offenders is not the same as tallying the labor required as part of the production process, if only because there is no indication of how many hours of labor the co-offenders contributed to the actual growing process (if any). The production facilities that were discovered and raided may not be representative of the larger population of growers. Finally, the total number of observations is not large (less than 100). For these reasons we do not directly use these figures in our analysis, but they do suggest that the relationship between labor input and production output warrants a closer look than the simple proportionality that we assume below.

Fortenbery and Bennett (2004) examine the industry for the production of commercial hemp. The economics of producing cannabis for hemp differ from production for purposes of consumption, but given that similar (but not identical) plants are involved, some similarities are to be expected in the cultivation stage. Greater differences in

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[9] Bouchard (2008) estimates an affine relationship between the number of co-offenders and the number of plants seized. Finding a positive intercept term, which he does for all three production modalities, ensures that the average number of co-offenders ("workers") per plant is decreasing in total output.
[10] We are skeptical that the simple affine form of the model (linear in the number of plants and an intercept) would predict actual labor usage well at small scale. The model implies that to cultivate the first plant takes almost three workers. It is better to view the model as a linear fit to the data that locally approximates the actual relationship between labor and production in the region of the observed quantities.

methods and costs appear in the harvesting and processing stages. Fortenbery and Bennett (2004) note processing technology for fiber hemp is relatively labor and resource-intensive, making the potential profitability of hemp production in the US questionable. The processing of cannabis for marijuana has also been labor intensive (Caulkins, 2010). The more labor intensive an aspect of the supply chain is, the less it will contribute to economies of scale, as the amounts of labor required are typically proportional to the quantities of product involved. On the other hand, labor intensive production steps are more likely to undergo technological and process innovation and a longer-term increase in the capital to labor ratio (the potential for automated trimming being a good example).

We suspect that in the long run, legalized production and processing of cannabis will significantly reduce, perhaps drastically so, the amount of labor needed as the industry becomes more capitalized. That has been the trend in general agricultural productivity.[11] However, the mechanization of processing by itself does not necessarily imply economies of scale in the long-term perspective. Although capital costs may be fixed in the short run, leading to short run economies of scale as the fixed capital cost is spread out over more production, in the long run nearly all inputs are variable. Furthermore, even when large expensive machinery is required to minimize production cost, economies of scale do not always result (Kislev and Peterson, 1996), as discussed in the next subsection.

Literature from agricultural economics

Schumacher and Marsh (2003)

Ideal for our purposes would have been to find a high quality, peer reviewed econometric study estimating the cost function for cannabis production. No such study—or, indeed, any econometric study—exists of which we are aware. However, if, at least for our greenhouse scenario, we expand our product from cannabis to "plants grown in greenhouses" then we can draw on the excellent study by Schumacher and Marsh (2003). The authors surveyed producers in the floriculture industry with the intent of assessing economies of scale. They coupled their survey data on input usage and output with prices for labor, materials, and energy gleaned from various sources to estimate the industry cost function. They apply state of the art econometric techniques for estimation and inference to refine their model, and then derive the implied economies of scale. They report their results in the form of an elasticity. The elasticity of cost with respect to quantity produced ("cost elasticity"), a positive number, tells us in percentage terms how much cost rises when production rises by 1%. Thus, when there are no economies of

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[11] In North America, agricultural output per worker rose from about $20,000 in 1963 to over $60,000 in 2003 (both in 2000 dollars). See Figure 8 of Pardey, Alston, and Ruttan (2010).

scale, the cost elasticity is 1.0. If there are economies of scale, the cost elasticity is between 0 and 1. Their calculated cost elasticity is 0.827. This figure means that when output rises by 1%, costs rise by 0.827%, implying that there are mild yet non-negligible economies of scale in floriculture.[12] The 90% confidence interval for the cost elasticity is [0.822,0.831], indicating the high degree of statistical precision they obtained. It is important to realize that Schumacher and March's finding of economies of scale for floriculture is not driven by their assumed functional form for estimation; had their data been different, their same method could have led to a finding of diseconomies of scale, or no economies of scale at all. The nature of an elasticity makes it a particularly useful summary statistic for our purposes, since elasticities are unit-free and we need not consider differences in how cannabis and floriculture production are measured.[13]

Kislev and Peterson (1996)

We also searched for general perspectives on economies of scale in agriculture. Kislev and Peterson (1996) argue that significant economies of scale in agriculture are unlikely. As they explain, scale economies "usually stem from the lumpiness or indivisibility of fixed capital" but that in the long run, indivisibilities are hard to find on the farm. Tractors and other machinery come in virtually any conceivable size, from hobby size to behemoths purchased only by the largest multi-state agribusinesses. Furthermore, "in the few cases where large machines are the most efficient...rental markets develop." That is, contractual arrangements among farmers may be expected to arise to minimize cost in the industry, regardless of the size of individual producers.

Another potential indivisibility is with labor. This arises in our context below with management labor for small operations. Kislev and Peterson (1996) point out, however, that potential indivisibilities in agriculture are smoothed out by options such as part-time farming and judicious use of seasonable agricultural labor for hire. Kislev and Peterson (1996) conclude "among the conventional inputs of land, labor, and capital, long-run indivisibilities should not be given serious consideration as a source of economies of scale."

It is hard to reconcile these conclusions with the observed domination of American agriculture in the heartland by giant farms of 1,000+ acres. Some of the consolidation into

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[12] The figure is calculated at the average values of output and input quantities in their sample, and thus is a summary statistic for elasticity.

[13] One factor that limits the usefulness of these estimates is the magnitudes of the scales involved. A relatively small-scale flower farm operates on a larger scale than a typical marijuana cultivator. You will not find any large economies of scale by observing existing small flower producers, for instance, because any producers too small to take advantage of a drastic economy of scale would have already been driven out of business.

large-scale operations might be explained by the professionalization of operations for large versus small-scale farmers. And agricultural machinery is becoming increasingly more computerized. A GPS satellite positioning system and a computer guided planter, for example, cost the same on a small or a big tractor.

Implications for economies of scale

Synthesizing the literature reviewed above, we conclude that while there are potentially some areas of cannabis production that exhibit economies of scale, 1) no one has yet performed calculations to directly assess them, and 2) we should maintain a healthy skepticism toward finding significant economies of scale. A few specific finding from the literature affected our calculations more directly. In section V.B.2.d) below we followed up on Denman and Cooley's (2013) assertion regarding quantity discounts for electricity, and found that they have the potential to create relatively large economies of scale at the low end of the scales of operation we consider. Drawing on the ideas of Kislev and Peterson (1996) described above, we will treat management labor as fully scalable, along with other types of labor. In this we depart from some of the other cost estimates performed in this area (e.g., the Solstice report).

For our greenhouse growing scenario, given the paucity of available data specific to cannabis production, we will instead rely heavily on the cost elasticity estimate of Schumacher and March (2003). See section V.B.3) There is some tension between Kislev and Peterson's (1996) contention that there are no great economies of scale to be expected in the long run in agriculture and the thoughts of our survey respondents on the one hand, and our use of Schumacher and Marsh (2003) cost elasticity on the other. We take a middle course between these two poles by splitting the difference and using an assumed cost elasticity of 0.913 instead of Schumacher and Marsh's (2003) estimate of 0.827 or the elasticity of 1.0 that would obtain under no economies of scale. We recognize that these estimates are not ideal, in that they derive from other crops and from mature industries, whereas legal marijuana is a brand new industry, but they offer a starting point for our analysis.

Description of data and methodology

In this section we describe our data and how we make use of it. Our goal is to estimate costs for two scenarios: indoor production with artificial lighting and greenhouse growing. For simplicity we refer to the former as the "indoor production scenario", even though greenhouses are not outdoors.

Data

We draw assumptions and data from three main sources for our work: Denman and Cooley (2013) (the Solstice report), Caulkins (2010), and Schumacher and Marsh (2003). Our original intent was to use primary data from our new Marijuana Producer Survey, but we did not receive enough survey returns within time to construct our models and had to rely on other sources for model development. The first two of the above sources are bottom-up accounting estimates of production costs for producing cannabis. Each is created using the authors' detailed knowledge of the production process and the costs it entails. Neither, however, focuses mainly on economies of scale, our primary issue. Schumacher and Marsh (2003) on the other hand, as described above in the literature review, take economies of scale as their main interest and estimate a cost elasticity for greenhouse growing (for floriculture, the growing of flowers and plants for sale to nurseries and other retail outlets).

We use the Solstice report, supplemented by Caulkins (2010), to estimate the production cost of indoor growing under artificial lighting at various scales.[14] Similar to their work, we build this part of our cost model from the bottom up, with detailed calculations involving wages for various types of work, the prices of plants, materials, and equipment, likely relationships between inputs and output, and fixed costs such as rent and insurance. The Solstice report provides two estimates for indoor growing: a 1,500 square foot (sf) facility and a 10,000 sf facility.[15] Their data have the twin advantages of coming from active, current operations and being specific to the Seattle area. They did not consider greenhouse growing.

We have since compared the results of our marijuana producer survey to the other sources. The results of the surveys returned are in line with those produced by the other authors, and we use them to verify inputs.

Description of sample:

We have responses from a total of 186 marijuana producers. Responses were solicited through a trusted network. Figure 1 describes the type of cultivators included among the respondents.

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[14] An important difference between estimates produced by Caulkins and those produced by Solstice is Solstice provides estimates of current production costs, whereas Caulkins models likely future costs after innovation has permeated the industry.

[15] The facilities from which the production and cost figures are calculated were actually 1,000 sf and 14,000 sf in size. The report's authors adjusted the numbers so be applicable to 1,500 sf and 10,000 sf.

Figure 1: Marijuana Producer Survey Respondents: Type of Cultivation
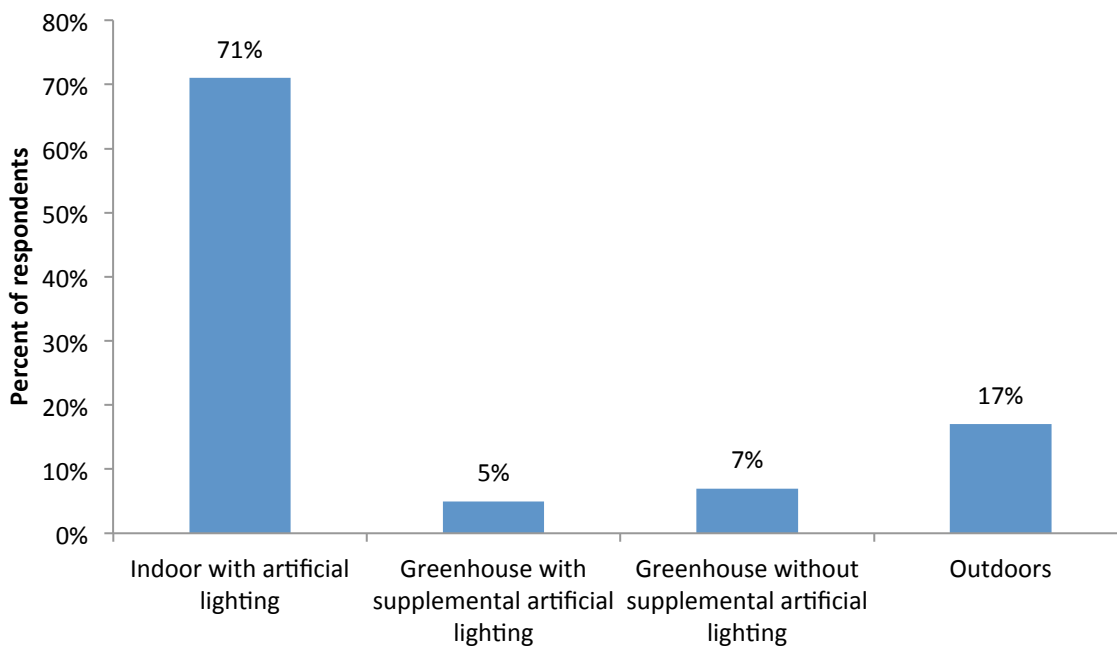
Growing operations varied significantly on scale. The size of outdoor grows ranged from 50 to 200,000 square feet (with an average size of 11,000). The size of indoor grows ranged from 20 to 30,000 square feet (with an average size of 980).

Implications for the indoor production scenario

We carefully examined their figures and calculations, with a particular eye toward identifying where the costs of running the larger facility were less, in proportional terms, than the costs of operating the small facility. Analysis of the survey responses showed that many parts of the relationship between the scale of the indoor operations and cost are indeed likely to be proportional. For instance, short-run variable costs such as labor for trimming, water, soil, CO_2, nutrients, and pesticide scale up and down directly with the size of the operation.[16] Moreover, many of the costs that are considered fixed by the Solstice report, such as equipment (e.g., for cultivation, lighting, and nutrient delivery), genetic stock for startup, rent, insurance, and management and general labor, appear to be proportional to scale.[17] Some of the components contributing to the assumed

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[16] We found no evidence that growers on the large end of our scale would be able to command discounts on input prices; large indoor cannabis growers are still small compared to other agricultural establishments in general. By comparison, about one-quarter of floriculture greenhouse growers are larger than 500,000 sf (Mateo, 2008).

[17] Such costs can be properly viewed as fixed in the short run but variable in the long run, which we explain further below.

construction of the facility (design, plumbing,[18] and carpentry costs, in particular) also are in proportion to scale, or nearly so.[19]

There are a few sources of economies of scale we found in the Solstice report. The electrical and HVAC work required many fewer hours/sf for the larger facility than for the smaller. The fees for the construction permits are also sublinear in project size. However, the latter parts are relatively minor components of overall cost, and so do not create strong economies of scale in the indoor production process.

Unexpectedly, there are two sources of diseconomies of scale in the Solstice figures: security system installation (for which the diseconomies are mild) and general contracting hours in the construction of the facility. The latter is problematic for our purposes, because the larger facility is only 6.7 times larger than the smaller operation, yet is assumed to have 30 times as many hours needed for general contracting. Presumably their figures in this regard are driven by idiosyncratic features of the actual facilities constructed from which they drew their numbers; there is no apparent reason why every larger facility should require so much disproportionate effort in general contracting when no similar diseconomies are found in any other component of the construction costs. We also examined preliminary survey results on startup costs (*int. al.*) from other BOTEC consultants (Zamarra, 2013), and while we found considerable variation in costs per sq. foot, particularly at the lower end of the size spectrum of those surveyed, there was no indication of such huge (or indeed, any) diseconomies of scale. Thus, we did not rely on the Solstice figures as is, but instead assumed the general contracting hours were proportional to scale, in the absence of better information (details are contained in the next section).

We identified two additional sources of economies of scale for the indoor scenario: the LCB license and the discounts available in electricity tariffs for larger scale operations. In our analysis, we use LCB's announced renewable license fee of $1000.[20] If someone has two licenses (producer and processor) then this would be doubled. The flat fee mirrors LCB's license fees for liquor sales, it appears that the practice is to set a single fee for a license for a particular type of establishment, but not to vary the cost of the license within

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[18] The Solstice report contains what appears to be a typographical error in the plumbing hours for the larger facility. The report states 40 hours are needed for the 10,000 sf facility, whereas 60 hours were needed for the 1,500 sf facility. If the 40 were actually 400, however, then the figures are directly proportional to size. We assumed 400 was actually meant.

[19] All references to "construction" for the indoor facility refer to modifying an empty warehouse space. Costs for the construction of the warehouse or bare industrial space itself are assumed to be included in the rental charges.

[T] There is also a one-time $250 license application fee.

an establishment class by retail volume or sales.[21] On the production side of the liquor market, LCB license fees do vary by scale in some cases, but only very coarsely. For example, wineries producing less than 250,000 liters per year pay $100 for their license, while larger wineries pay four times as much. For our calculations we assumed that the LCB would charge a fee of $500 for indoor production and twice as much for greenhouse operations, which we generally expect to be larger. These fees, while arbitrarily assumed, are higher than charged for craft distillery licenses ($100) but less than brewery licenses ($2000), which roughly span the charges for licenses. The nature of an annually recurring fee is that of a fixed cost, even in the long run. As such, it will contribute to economies of scale even in our long run analysis.

In the indoor production scenario, the other source of potential scale economies that we added (beyond the Solstice analysis) is quantity discounts for electricity.[22] We examined tariffs from Seattle Light and Power, the electricity utility in the Seattle area, and found that for commercial customers on a particular tariff (small or medium), there are no quantity discounts. That is, both of the two relevant tariffs (those for small and medium size business customers) have a single price for electricity demand and usage, but the medium-size tariff is significantly cheaper than the tariff for small business customers. The quantity discount comes from creating enough demand load often enough during the previous billing year to qualify for the medium-size tariff. The threshold is 50 kW of demand, which may be lower than the demand of the smallest of the facilities we consider (our analysis extends down to 1,000 sf indoor operations). If that were the case, then these smallest operators would face a significant disadvantage in electricity prices. Since electricity usage is a major cost for indoor cannabis growing, scaling up to take advantage of the more advantageous electricity tariff create nontrivial economies of scale at the low end of our range. Based on the figure for electricity usage in the Solstice report, we estimate that the 50 kW demand threshold is met when the indoor facility size is 1,350 sf.[23] While this particular threshold is specific to one utility, several other utilities in the state offer similar price structures, albeit with other thresholds and rates.

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[21] For example, beer and wine specialty shops, which may be expected to have smaller sales volume than grocery stores, pay $100 for a liquor license in Washington, regardless of the size of the shop, while grocery stores pay $150 (Washington State Liquor Control Board, *Retail Liquor License Endorsement Description and Fees Information*, available from http://liq.wa.gov/publications/licensing/LIQ_180_Retail_Desc_Sheet-6-14-12.doc (as of June 1, 2013)).

[22] The Solstice report mentions price discounts for electricity, but assumes all facilities will be large enough to qualify.

[23] The calculation assumes a demand load of 37 watts per sf of total facility size. We arrived at this figure by examining electricity costs in the Solstice report. The figure is in accord with Caulkins' (2010) figure of 40 watts per sf and is at the upper end of the range implied by a "growers' rule of thumb" in Bouchard (2008). That rule of thumb is that one 600- or 1000-watt metal halide/HPS amp will produce one pound of cannabis. Working through the figures for our scenario, that rule implies a total demand load of 32.3 (with

Implications for the greenhouse production scenario

For greenhouse growing of cannabis, finding detailed cost information comparable to the Solstice figures for indoor production was very problematic. For that reason we do not attempt to estimate economies of scale from a detailed, bottom-up estimation of the costs of running various sizes of operations. Instead, we estimate the costs involved in running a greenhouse facility of typical size, which we take to be an acre of rented farmland housing a greenhouse occupying 75% of the space (yielding about 33,000 sf of greenhouse footprint). We chose this as our typical size as a compromise between typical greenhouse sizes in the cannabis and other agricultural industries. (Though 33,000 sf may be on the high end of current greenhouse cannabis operations, it is actually on the low end for greenhouse operations producing flowers, vegetables, and fruit.) By comparison, floriculture establishments averaged about 302,000 sf on the West Coast (Evans, 2002). Our greenhouse construction cost estimates come from a variety of sources, as we explain further in section B.3

Given this baseline size and its estimated costs and output levels, we drew on the work of Schumacher and Marsh (2003) to inform estimates for the cost curve at other production levels. As mentioned in section IV.C, we made use of these authors' estimated cost elasticity by taking the midpoint between their estimate of mild economies of scale and no economies of scale. We then fit a variable cost function possessing this elasticity and passing through the quantity and cost estimated for our typical greenhouse. Additionally, we add the LCB license fee and security monitoring on top of the estimated variable cost curve. Thus, considering our lack of detailed data on greenhouse cannabis production at various scales, we instead use Schumacher and Marsh's sophisticated econometric estimate of cost elasticity, calculated from a large sample of actual greenhouse growers of somewhat similar crops (flowers and plants). The results are meant to be illustrative, and can be refined as additional cost data on greenhouse growing of cannabis become available.

Methodology and assumptions

In this section, we describe our approach for synthesizing data from multiple sources and methods for converting accounting costs into economic costs. Our analysis rests on the notion of *long-run average cost* (LRAC) from economics. In economics, analysis of the costs of using scarce resources—be they labor, materials, money sunk into capital, or managerial expertise—includes considering what the decisionmaker gives up by not making an alternative choice. Thus, economic costs are opportunity costs—the value of

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600 watt lamps) to 53.9 (with 1000 watt lamps) for our 1,500 sf facility, which in turn equates to 22 to 36 watts per sf of total facility size.

the best forgone alternative when the choice to use a resource is made. While the accountant's and the economist's definition of costs coincide for many items, such as wage labor and consumables like materials, the treatment of the costs of durables, unpriced inputs such as owner-supplied management, and rental deposits differs. To perform the long-run industry analysis appropriate for evaluating various licensing scenarios, we adopt the economist's approach.

In the work that follows we will consider scenarios with various time horizons: one, three, five, and ten years. For the indoor scenario we additionally consider a 30-year horizon (the horizon that minimizes LRAC, given the assumed life of capital and equipment, as explained in section 1.b) below).

Methodology

While the details of the costs we include are contained in the following subsections, we describe here the main points where the accounting and economic treatment of costs differs. We also discuss how our approach to costing differs from a traditional discounted cash flow (DCF) analysis.

i. Opportunity costs in the models

There are three cost elements in our work where economic costs are treated quite differently than accounting costs: the opportunity costs of capital and other durable input goods, unpriced contributions of labor, and the value of money tied up in rental deposits.

The rental rate of capital, also known as the user cost of capital, is the opportunity cost of having a business' investment money tied up in structures, machines, and equipment instead of in another investment earning the currently available rate of return. A standard formula from microeconomics shows that the user cost of capital, expressed as a rate per dollar of capital, is equal to the sum of depreciation and the return that would be earned on similarly risky investments. That is,

$$r = d + i$$

where r is the rental rate of capital, d is the rate of physical and financial depreciation, and i is the rate of return on similarly risky ventures.[24] The economist's treatment of depreciation is the decline in the market value of an asset during a period.[25] That decline in value stems from two sources: the physical diminution of the capital stock due to machines wearing out and the pure change in value due to price depreciation.

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[24] See, for example, equation 23.16 of Nicholson (1989).
[25] This may be quite different than the IRS depreciation rates used for tax purposes by accountants.

There are two capital asset classes in our model: 1) the initial construction of the facilities and 2) the durable equipment used for cultivation, environmental and lighting control, nutrient delivery, and finishing. For the capital embodied in the facility construction itself, we treat the indoor facilities differently than the greenhouse facilities. The Solstice report shows that indoor facilities require a great amount of purpose-driven construction work to repurpose a bare warehouse space into a production floor for growing cannabis. Given the highly specific nature of these alterations, we have made the assumption that there is no market resale value to the improvements. That is, we treat the construction cost for indoor operations as a *sunk cost*—none of the construction cost is recoverable should the business attempt to cash out and leave. While this assumption is extreme, we adopt it for the following reasons. First, the sunk nature of the cost most heavily influences our shorter-term scenarios. Once the horizon of the economic analysis extends to or beyond the lifetime of the capital, capital cost becomes one more recurring cost. Second, we envision in our short-term scenarios (say, the one and three year scenarios in particular) that the reason the business is closing up so quickly is due to federal intervention and seizure of assets. If that were the case (and all that matters is that this would be the firm's *ex ante* expectation of why they would close so quickly), then there would presumably be no opportunity to sell the structure with its cannabis-production-specific improvements to a similar outfit. Although the value of the construction capital depreciates 100% immediately, that reflects price depreciation instead of physical depreciation. For the latter, we set the capital life to 15 years, based on IRS assumptions for agricultural and horticultural structures.[26]

For greenhouse construction, on the other hand, a valuable fraction of the total investment is the greenhouse itself, which may have value when put to other uses.[27] Therefore we do not assume that greenhouse construction is a fully sunk cost. Instead, we assume that only 50% of the value depreciates immediately, and the remaining value decreases linearly (straight-line depreciation for the remaining value) until the end of the life of the capital. Instead of using a 15-year life for greenhouses, in line with the general IRS assumption for agricultural and horticultural structures, we reduced the useful life of a greenhouse to 10 years. This reflects the fact that many modern greenhouse are not the "walls of glass" that often come to mind with the term (known as a "glasshouse" in industry parlance), but instead are structures covered with translucent or transparent plastic sheeting. The life of the plastic sheeting may be as brief as three years (WVUES,

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[26] In particular, 15 years is the "class life" for any "single purpose agricultural or horticultural structure," per IRS Pub. 946, chapter 4 (2012).
[27] The thought may occur to the reader that, by similar logic, the warehouse itself may have resale value in the indoor growing scenario. However, along with Solstice we assume the warehouse is rented, not purchased, and therefore the "resale value" of the warehouse is embodied in the rent and need not be considered separately in the analysis.

2013), depending on the material used, even though the metal ribbing of the structure lasts far longer. Ten years is our compromise figure.

Both indoor and greenhouse production make use of durable equipment such as fans, temperature regulators, and nutrient delivery tubing and pumps. Since much of this equipment would have legitimate use in many other agricultural and industrial applications, we assumed that only 50% of its value is sunk.[28] As with the greenhouse capital embodied in the structure, we take a straight-line depreciation for the remaining value until the end of the useful life of the equipment, taken to be 10 years. The latter figure is chosen in accord with IRS assumptions for agricultural equipment.[29]

Given that cannabis production represents considerable legal risks even under the I-502 market, i (the rate of return on similarly risky ventures) represents not just the interest rate but also an upward adjustment to account for the additional risk. We choose i = 10%, but this parameter can be easily varied in the analysis. This rate reflecting the opportunity cost of sinking money into capital is applied to the undepreciated value of the capital remaining midyear. For example, in the one-year scenario, since indoor construction fully depreciates right away, there is no midyear value, and the rate i is applied to a value of zero yielding zero opportunity cost. Conceptually, this is because with sunk costs there is no opportunity to sell the asset and use the money elsewhere. For equipment or greenhouse construction, on the other hand, the value remaining in the middle of the first year is 50%, and the opportunity cost associated with that value is therefore $0.5i$ times the original cost of the asset. In scenarios with longer horizons, conceptually the treatment of years after the first year is similar: rate i is applied to remaining midyear value.[30]

ii. The long-run average cost approach (LRAC) vs. discounted cash flow (DCF)

Our methodology is aimed at estimating long run economic costs. One reason for the focus on the long run is that we are interested in questions of the sustainability of particular industry structures under various licensing schemes. Another reason is that by looking at the long run, certain costs that are fixed in the short run become variable in the long run. Examples of such costs are those that the Solstice report call "fixed costs": rent,

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[28] Our intent in immediately depreciating 50% of the value of equipment is to reflect 1) the change in market value of "new" versus "used" industrial equipment, even when the latter is fairly new, and 2) the costs that would be entailed in finding a buyer for the used equipment, uninstallation, shipping costs, etc.
[29] In particular, 10 years is the class life for "agricultural machinery and equipment," per IRS Pub 946, chapter 4 (2012).
[30] We simplified this procedure in one respect for purposes of simplifying the calculations for scenarios with horizons greater than one year. Instead of applying rate i to actual midyear remaining asset value, each year after the first we apply it to the *average* of the midyear values that obtain during the remainder of the scenario. This simplification affects the calculations only a small amount, and (most importantly for present purposes) does not alter the overall shape of the LRAC curves.

insurance, security monitoring, and labor categories of management and general farm work (not including trimming). In a short-run sense, these indeed are fixed, as they do not vary directly with the size of the harvests, *given that* 1) a lease on a particular size building is in place, 2) insurance has been purchased for a six-month period, 3) a manager shows up for work every day regardless of last month's plant growth, and so on. However, in the long run all these can be treated as variable costs—appropriately sized buildings and structures can be rented or built to accustom changes in planned production changes, just as insurance policies and management talent (and therefore cost) can be reworked as the scale of the operation changes, and so forth. Thus where other analyses have distinguished between variable and fixed costs on the basis of whether they vary with production during the year, we instead refer to the former as short-run variable costs and the latter as long-run variable costs (as shorthand for "costs that are fixed in the short run but varying in the long run"). In the long run, the only truly fixed—that is, scale-independent—cost is the assumed cost for the LCB license.

Given our interest in assessing costs and prospects for the industry as a whole, the long run economic approach is warranted. However, certain aspects of our methodology may appear unusual to those schooled in traditional MBA-style discounted cash flow (DCF) analysis. In a DCF analysis, the costs and payoffs over the life of investment are discounted to present value, and the project is deemed worth taking on if the net present value is positive. In contrast, our method does not convert expenditures and revenue to present value. Instead, we treat the length of the scenario under consideration as a single time period, aggregate the costs, divide by the total production in the period, and finally divide the former by the latter to arrive at long-run average cost. By abstracting away from the details of net present value at any particular point in time over the life of the capital and equipment, we are able to average out the fixities in (i.e., the "lumpiness" in costs for) construction, capital, equipment, depreciation, and labor. Furthermore, given long enough horizons, we can treat sunk costs as recurring costs. This is the standard approach in, for example, regulatory economics and accounting for industries with long-lived capital, such as telecommunications and electricity. Thus we will extend the horizons of our modeling to the minimum number of years required for all capital and equipment to simultaneously reach the end of its expected lifespan. This requires a horizon of 30 years for the indoor scenario (the lowest common denominator of 10-year equipment and 15-year facilities) and 10 years for the greenhouse scenario (the life of both facilities and equipment). Scenarios with the longest horizons minimize LRAC for

any given amount of production, because all productive use of the capital has been wrung out of it.[31]

Finally, we note that our economic approach glosses over many considerations that a small operator may be forced to deal with in actuality. We assume that the financial capital markets function smoothly, so that money can be found to finance startups at our assumed rate of i. However, given that we have risk-adjusted i to be on the high side, we at least implicitly subsume some financing problems. [32]We also do not consider any additional problems producers might have in procuring production or agricultural space, for instance if landlords and landowners prove to be reticent to rent to cannabis producers. Furthermore, we set aside any speculation about unequal rates of inflation across the classes of goods, services, and inputs that are relevant to costs and revenues of growing cannabis. Instead, we treat real prices as unchanging in all scenarios, regardless of horizon.[33]

Assumptions and costs for the indoor production model

To compute average cost for the industry, we must make explicit the link between inputs and outputs. That is, we must posit a production function. Then we must estimate cost. Production cost in our scenarios stem from four sources: capital costs, long run variable costs, short run variable costs, and the long run fixed cost of the LCB license. In this section we describe the production process we assume and break down each of the types of cost for the indoor production scenario.

Before proceeding, it is important to recognize two things at the outset. First, as with other work in this area, we are forced to make assumptions about many aspects of the production process and the costs associated with production. While we make our best efforts to use reasonable values in all cases, there will be an inescapable amount of approximation error in our final results. Second, and more importantly for our present purpose of assessing economies of scale, the *shape* of the cost function is more important than its *level*. Changing many of our assumptions would change the level of the average cost function—i.e., shift it vertically—without changing its shape (or changing it little). However, it is the shape of the average cost function that determines whether there are economies of scale.

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[31] Remember that our assumed depreciation is front-loaded. This means that most of the economic cost of the asset is "paid" near the beginning of its life, which in turn means that the asset is relatively inexpensive to use at the end of its life.

[32] A risk-adjusted interest rates seems justified given the risks involved in investing in the marijuana industry. Our survey showed that access to capital presented an important challenge to many marijuana growers and for many it was an impediment to increasing the size of their operation.

[33] General inflation that affects all costs and revenues of production equally has no impact on our analysis, since an economic analysis is always conducted in real (inflation adjusted) prices.

i. Production

We must first make clear our assumptions regarding the usage of the space rented. After reviewing similar work by others (Caulkins, 2010; the Solstice report) we settled on the assumption that 70% of the total space rented is used for production, with the balance being dedicated to offices, bathrooms, breakrooms, and the like. Of the 70% devoted to production, only 70% of that space is used as growing area ("canopy"), with the other parts of the production floor set aside for walkways, etc.[34] Thus, for example, in the 1,500 sf facility, about half of the space (actually 49%, or 70%*70%) is used for canopy. However, since the relationship between growing space and total space is assumed to be proportional (at least within the range of sizes considered in the scenarios), costs that are proportional to canopy area are also proportional to total area, and vice versa.

We take production numbers exclusively from the Solstice report. Based on actual production numbers from their sources, their 1,500 sf facility produces an average of 8,148 grams (nearly 18 pounds) of cannabis per month. This amount comes from an assumed four harvests per year and each plant occupying nine sf. The total annual product represents 5.4 grams per sf of total space. To allow comparison with other production estimates, note that the Solstice report implies 33.26 grams (or 0.073 pounds) per sf of canopy *per harvest*. In contrast, Caulkins (2010) cites studies a study from the Netherlands from small indoor growing operations showing production averaging 0.105 pounds per sf of canopy per harvest. That difference is likely accounted for by the fact that the plants in that study (Toonen *et al.*, 2006) were planted much more densely than the Solstice report assumes—1.4 plants per sf in Toonen's study and 1 plant per 9 sf in the Solstice calculations. In a more recent survey of production studies, Caulkins (2013) summarizes the evidence as pointing toward 40 grams (or 0.088 pounds) per sf per harvest for indoor growing. To facilitate comparison with other studies, we will also state the yields from the Solstice report in various other metrics: 0.073 pounds per sf of canopy per harvest, 133 grams per sf of canopy per year, 65.2 grams per sf of total facility space per year, 93.1 grams per sf of production space per year, 0.14 pounds per sf of total facility space per year, and 0.66 pounds per plant (per harvest).

Given that our production numbers are a bit lower than these other estimates, we briefly consider here the impact of our assumptions. If production volumes were higher, then it would have the effect of lowering average capital cost and some components of average variable cost. That is, higher amounts of production could result from employing the same amount of capital or bearing the same level of certain long run variable costs (such

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[34] We suspect that setting aside 30% of the growing floor for walkways is overly generous compared to current illicit and semi-licit operations. However, with legality will come adherence to OSHA and other state, county, and city rules on safe and appropriate industrial layout, which will presumably lead to less crowded production floors.

as rent and management), thereby lowering these variable costs per sf. On the other hand, short run variable costs that are proportional to output (such as electricity and trimming labor) would remain unchanged in average terms. Finally, long run fixed costs would fall in average terms. Given that the economies of scale we identified above are generally found in capital costs and long run fixed costs, underestimating production therefore has the effect of overstating potential economies of scale. However, since we generally find only mild economies of scale in indoor production, it does not appear that modest increases to our production figures would change our conclusions.

ii. Capital cost

Here, the term "capital" applies to construction costs, equipment, and initial genetic stock. These are the start-up costs from the Solstice report, with two modifications. First, in scenarios with horizons that leave some capital less than fully depreciated, the full cost of capital is not included. Second, as described above, we included the opportunity cost of the money invested in undepreciated capital. Total value of capital before any depreciation is in Table V.1. This and subsequent tables show costs for two facilities, in the same sizes as the Solstice report: 1,500 and 10,000 sf. It is important to realize, however, that we calculate these costs as a function of facility size, and assume that our calculations are good for any indoor facility between 1,000 and 15,000 sf.[35] Unless otherwise noted below, for each of the line items in Table V.1 we assume that cost can be linearly interpolated and extrapolated across the 1,000 to 15,000 sf range, based on the costs calculated for the 1,500 and 10,000 sf facilities.[36]

The first component of capital cost is for construction: rendering bare warehouse space into a production floor. The labor categories and hours listed in Table V.1 are taken directly from the Solstice report (but see footnote 17), with the exception of general contracting. As mentioned above, we found it best to modify the hours required for general contracting to avoid the implied huge diseconomies of scale in the Solstice hours. Instead, we used Solstice's numbers to calculate the linearly interpolated number of general contracting hours for a 5,000 sf facility, and then assumed that general contracting costs were proportional to facility size. The wages for the construction categories are median values for Washington State, available from a spreadsheet from the Washington Employment Services Division.[37] Since what customers pay for construction

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[35] We chose not to extrapolate the indoor figures beyond that range because doing so would take us too far from the Solstice sizes upon which we base most of our calculations.

[36] The assumption of linear interpolation does not by itself create economies or diseconomies of scale, because linear interpolation of cost between the two scales of operation implies that cost is affine (not linear) in square footage, and therefore not necessarily proportional to the scale of operation.

[37] The spreadsheet is *Washington Statewide 2012 Occupational Employment and Wage Estimates*, which includes all counties) These do not necessarily match those from the Solstice report, either due to more recent wage data or choice of different occupational categories. We matched the occupation in the Solstice

work is more than the wages paid to construction employees, we followed Solstice in arbitrarily marking up wages 200% to account for payroll taxes, benefits, overhead, materials used in construction, and profit.[38]

Construction costs include both labor and building permits. The exact cost of such permits will depend in which city or county the facility is constructed. We followed Solstice in assuming a Seattle location but recalculated their permitting costs assuming the work would be treated as renovation (rather than construction), since the basic industrial space is assumed to be rental of an existing structure. Unlike the other components of cost in Table V.1, the fees for the building permits are not interpolated, but are calculated using a fee calculator from the Seattle Dept. of Planning & Development for every possible facility size.[39] The fee structure displays some economies of scale.

The second component of capital cost is for equipment. The categories and costs for equipment are taken directly from the Solstice figures for the 1,500 sf facility, and are assumed to be proportional to facility size.[40] A tacit assumption underlying proportionality is that over the range of facilities considered here, the discrete nature of some of the equipment is not important[41] and that larger facilities will not be offered purchasing discounts beyond what smaller facilities receive, as discussed above.

The third component of capital cost is for the initial stock of cannabis plants with which to begin production. Here, we defer to the expertise of the authors of the Solstice report and their grower contacts, and assume the same sizes, quantities, and types of plants will be needed to begin operations. Given the assumed "perpetual harvest" model in the Solstice report, these include potted cannabis plants of various sizes (including some larger, more expensive plants to hasten the time to first harvest) and rooted clones. After the initial expenditure on plants, we assume that the future needs for genetic stock are

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report to the closest category in the WA ESD spreadsheet. Those categories that weren't exact matches it occupation were: general contracting (for which we used wages for "general and operations managers"), design ("commercial and industrial designers"), and HVAC professional ("heating, air cond, refrigeration mechanics & installers").

[38] Although the Solstice report says wages are marked up 150% in their calculations, examination of the actual figures and the tables in the appendix shows that they actually used a markup of 200%.

[39] The spreadsheet is titled "Fee estimator (based on 2013 Fee Schedule)", from http://www.seattle.gov/dpd/cms/groups/pan/@pan/documents/web_informational/dpdd017615.xls. We entered the total figure for the value of the construction work as the value of alteration to an existing structure in the calculator.

[40] Here we depart from the Solstice report, where the authors multiplied the equipment costs from the smaller facility by a factor of 7, even though the larger facility is only 6 2/3 times as large. They state that "a factor of seven is used based on the 10,000/1,500 ratio with additional space found in large-scale efficiency," apparently without realizing that using a larger factor implies that there are *dis*economies of scale.

[41] That is, we assume away the problem of "scaling" 5 fan units down to 3.5 fans, for example. Given the abundance of makers, brands, and capacities of industrial and agricultural production equipment, we do not expect this to be an issue.

self-supplied through propagation. In the absence of other information, we do not assign a cost to such propagation, beyond that priced in the labor components of operations (below).[42]

The total values of capital installed at startup average $68.34/sf for the 1,500 sf facility and $64.99/sf for the 10,000 sf facility. These estimates appear to be in line with preliminary surveying of costs performed by other BOTEC consultants (Zamarra, 2013). Out of seven usable survey respondents, six reported startup cost per square foot of $57 to $71 (there was an additional outlier of $131), for a trimmed mean of $66.50.

iii. Long run variable costs

Certain costs are variable in the long run while fixed in the short run. These include rent, rental and security deposits, insurance, and certain forms of labor.[43] The figures for these are in Table V.2, and for the most part come from the Solstice report for what they term "fixed cost". The modifications we made were to assume that labor cost for management and janitorial work is proportional to facility size. The facilities Solstice examined in its report did not have these types of workers on payroll at the smaller facility, and so they did not impute a cost for them. Even if the smaller facilities do not actually have payroll expenses for janitorial or management work, there are still opportunity costs involved with the time devoted to these tasks, even if performed by an owner or other employee, and such costs should be included in an economic analysis. Therefore, we take the Solstice figures for management and janitorial labor at the 10,000 sf facility and linearly scale them for facilities of other sizes. While it may appear odd to assume that a 9,000 sf facility has "nine-tenths" the manager of the larger facility, we believe this is a good approximation reflecting that management may be shared between smaller facilities or how the manager's salary might change with the scale of his responsibilities. Similarly, assuming that janitorial work can be outsourced, it is reasonable to assume that contracts with firms providing janitorial services are roughly proportional to the work needed to be done, which in turn should depend directly on the size of the facility for the most part.

We assume that industrial space rents for $0.46/sf per month regardless of the size of the facility.[44] The range of operational scales we consider is relatively small within the context of the larger world of industrial and commercial real estate, and we did not find

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[42] We could assign an opportunity cost to the usage of internally propagated plants, if they could be sold to other growers instead of used internally. However, we do not have the information needed to pursue this facet of costs. Regardless, since this would be one more cost factor that is proportional to output, it would only change the *level* of the average cost functions, without materially affecting its *shape*.

[43] While one may quibble whether any particular type of labor is a fixed or variable cost in the short run (and therefore whether we should discuss it here or in the next section), the advantage of the long run approach is that the distinction makes no difference. Both are variable costs in the long run.

[44] Our source is the "direct asking rents" for first quarter 2013 from Cushman & Wakefield (2013). For comparison, the Solstice report uses a figure of $0.50/sf/month.

any indication that larger facilities should expect lower per-unit rental costs. The microeconomics of competitive capital markets implies that it makes no difference whether the operator of the facility owns or rents the building (from the long run economic perspective, that is), for if the building is owned then the rental rate becomes the opportunity cost of using the building instead of renting it to another user.

Assuming that in a standard rental contract the last month's rent must be prepaid and that a security deposit of size equal to a month's rent is required, then the contribution to economic cost of these two items is the opportunity cost of having that amount of money tied up, which is i per dollar per year.

The total of the long run variable costs works out to $14.62 per square foot of total size. This cost component is directly proportional to the scale of the operation.

iv. Short run variable costs

Costs that vary with production quantity even in the short run include labor and non-labor inputs. We follow the Solstice report in separating labor for general farm work and trimming (also known as "manicuring"). These costs are shown in the bottom part of Table V.2. The other inputs in this category are electricity, water, soil, CO_2, nutrients, and pesticide. As discussed above in section A.1, we use the tariffs from Seattle Light & Power for the electricity rates. The tariffs, coupled with our assumptions on demand load and usage, lead to prices that are proportional to the scale of operations within each tariff. Since both the 1,500 and the 10,000 sf facilities are on the same tariff, the costs in the comparison columns of the table are proportional. However, electricity is relatively more expensive for smaller facilities. The other non-labor inputs are all directly proportional to scale.

Short run variable costs sum to $53.37 per square foot of total size for facilities larger than 1,350 sf. For facilities larger than 1,350 sf, this cost component is directly proportional to the scale of the operation. For facilities smaller than that, which must be on the less favorable electricity tariff, short run variable cost is $59.21 per square foot of total size.

v. Long run fixed cost

We found only two costs that are fixed in the long run. The first is the LCB license, as discussed above. The other is security monitoring, which the Solstice report costs at $45/month regardless of scale. Even together, these costs compose a very small portion of total cost, and thus create only mild economies of scale in production.

Assumptions and costs for the greenhouse production model

As discussed above, we lack cost information for greenhouse production with as much detail as we have for indoor production. In this section we describe how we estimate the cost of running a greenhouse operation of typical size for growing cannabis.

Instead of the bottom-up cost accounting we perform for indoor growing operations, our approach for greenhouse costs is different. We simply do not have the data to try to directly estimate economies of scale for greenhouse operations. We instead calculate a reasonable estimate for a greenhouse operation of size 32,670 sf. We then assume that there are mild economies of scale in growing cannabis in greenhouses, as in floriculture.

i. Production

While greenhouses may be operated in urban and suburban settings, we assume that efficient greenhouse operations will be undertaken in rural (or semi-rural) areas. Due to zoning restrictions, urban greenhouses may need to be glasshouses, which are much more expensive to construct than modern agricultural greenhouses composed of poly film, woven poly film, or polycarbonate sheeting over metal framing. Therefore we envision the greenhouse production taking place on rented agricultural land. Each acre rented is assumed to be used 75% for the greenhouse itself, with the rest being used for paths and support areas. The scale of the greenhouse operation will always refer to the square footage of the greenhouse itself, although the full size of the parcel is used to calculate rental costs. For example, our one-acre typical setup encompasses a 32,670 sf greenhouse.

We assume that 65% of the space inside the greenhouse is used for canopy. This is at the low end of the 65-80% range we found in one source for general agricultural greenhouse production (WVUES, 2013) but slightly higher than the 60% assumed in Caulkins (2010). Thus the typical setup offers 19,602 sf of canopy. However, given the generally larger sizes of greenhouse and cheaper construction and rental costs per sf involved, we relaxed the assumption on the space required per plant. Instead of the 3' by 3' plot envisioned for each plant in the indoor scenario, we assume one plant per 16' in the greenhouse scenario.

We assume there will be two harvests per year, in line with Caulkins (2010). A greater number of harvests per year could be achieved with more use of artificial light, but then the cost advantage of greenhouse growing begins to evaporate. Yields are assumed to be 35 grams per sf of canopy, the rounded figure from our indoor scenario, since greenhouse-specific cannabis production studies appear to be nearly nonexistent.[45] For

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[45] You might expect lower sf yields for greenhouse compared with indoor, since greenhouse grows would tend to have lower-intensity lighting.

comparison with other studies, we will also state the yields in various other metrics: 0.077 pounds per sf of canopy per harvest, 70 grams per sf of canopy per year, 45.5 grams per sf of greenhouse space per year, and 0.100 pounds per sf of greenhouse space per year.

ii. Capital cost

Construction costs for greenhouses vary by type of construction, and a range of estimates is available in the literature. Caulkins (2010) mentions, without citing specific sources, a range of $5-12 per sf for construction cost for double walled polyethylene film greenhouses. WVUES (2013) cites construction cost that equate to about $13.30 in 2013 dollars (the actual costs cited are from 1990), but this includes equipment. About $8 of that amount is for the structure itself. At the risk of overestimating the cost for construction and equipment, we assume construction cost for the structure of $10/sf and an identical amount for equipment. Construction labor is subsumed into this cost, which is another reason we pick a number on the high end.[46] All costs for the typical greenhouse installation are in Table V.3. No building permit costs are included, since these structures are not for occupation.

For costs of genetic material, we borrowed from the Solstice figures for the indoor settings. The available growing space in the greenhouse on the 1-acre plot would allow about 1,225 plants to be grown in their 4' by 4' plots. With only two harvests per year and a greater dependence on the natural rhythm of the growing year, we did not assume that production was of the "perpetual harvest" variety. Therefore, no larger plants are needed at the beginning. We assume that plants in 1-quart pots will be purchased and planted, at a cost of $20 per pot. As with the indoor scenario, we assume all future plantings come from propagation onsite.

iii. Long run variable costs

There is a wide range of land rental rates we could have chosen. From a USDA survey for 2012, we find that irrigated cropland rents for between $60/acre in the northeast area to $562 in Adams County (all figures in the survey are county averages, although some counties are aggregated with others).[47] We take rent for agricultural land to be $566/acre per month. This figure comes from Neibergs and Waters (2009), and pertains to land used for growing asparagus and potatoes in rotation in Franklin County, Washington. This figure may be high for our purposes, to the extent that prime cropland isn't needed for greenhouse operations so long as soil is purchased separately, as it is with indoor

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[46] It is not always clear if construction estimates for greenhouse include labor cost, but at least some we examined do not.

[47] Figures are from the Cash Rents Survey performed by the USDA National Agricultural Statistics Service. See http://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Cash_Rents_by_County/index.asp.

operations. We may thus be understating the cost advantages of greenhouse growing over indoor operations.

For insurance, in the absence of other information we assumed that the same cost per sf of indoor growing applies to the size of the greenhouse. If insurance rates in agricultural areas are lower in general, as we suspect due to lower rates of theft than in urban areas, then again we may be overstating the costs.

For management cost we relied on the outdoor farming estimate in the Solstice report, which assumed that a 10,000 sf outdoor growing area requires 60 management hours/month. Thus, assuming proportionality as for the indoor scenario above, our typical installation requires 196 hours of management per month.[48] We assume no janitorial labor is required.

Similar to the indoor scenario, we assume that two months' worth of rent will be tied up in prepaid final month's rent and a security deposit. As before, the only economic costs here are from the opportunity cost of having that amount of money invested in the greenhouse operation instead of elsewhere.

The total of the long run variable costs works out to $4.20 per square foot of total size. This cost component is directly proportional to the scale of the operation.

iv. Short run variable costs

For the price of electricity, we did not use the Seattle-specific tariffs used for the indoor scenario, because we envision that greenhouse production is likely to take place in less urban parts of the state. Accordingly, we examined the statewide all-inclusive price of electricity for Washington State for commercial and industrial users. In 2012, Washington State electricity providers had average revenue of $0.0767/kWh for commercial customers and $0.0411 for industrial customers.[49] While cannabis growers would be considered industrial customers, we hesitate to adopt the lower figure. From our examination of electricity tariffs offered by various utilities around Washington State, it is clear that the largest industrial customers get significant discounts on their rates. However, cannabis producers will be nowhere near the demand loads necessary to procure electricity at the most-favorable rates. To avoid having this one assumption create a possibly artificial difference in cost between indoor and greenhouse growing, we took the average price per kWh from the indoor scenario (from the lower priced tariff): $0.0596.

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[48] As explained above, we don't take the proportionality literally; it is in part a stand-in for the higher salaries that management with more responsibility would be expected to earn.
[49] US Dept. of Energy, Energy Information Administration, Electricity Data Browser (http://www.eia.gov/electricity/data/browser/).

For electricity usage, we assumed that, subject to an arbitrary scaling factor α, the electricity needs of a sf of greenhouse are the same as those for a sf of production space in the indoor scenario. We chose α to be 25%, inside the range of 0 to 33% conjectured by Caulkins (2010). For the other short run variable inputs apart from labor (soil, CO_2, nutrients, pesticide), we generally assumed that the requirements per sf of canopy were the same as for the indoor scenario, with an adjustment made for the different footprints of the plants (9 sf in the indoor scenario versus 16 sf in the greenhouse scenario). The exception was for soil, for which we did not adjust for the different footprint of a plant. These are the other short-run variable costs are in Table V.3.

For general farm labor, we began with the figure from the 14,000 sf indoor source data in the Solstice report and scaled it according to the size of the greenhouse, subject to an arbitrary scaling factor β. Following the lead of Caulkins (2010), we set β = 50%. This resulting amount of labor is also consistent with the Solstice report's figures for their outdoor growing scenario, after adjusting for the differing number of crops in the outdoor grow. Trimming labor was taken to be proportional to production at the same rate of 41.43 grams per hour as used above.

v. The cost function

As mentioned in section IV.C, we made use of these authors' estimated cost elasticity by taking the midpoint between their estimates of mild economies of scale and no economies of scale. We thus assume that cost elasticity is 0.913 for greenhouse growing of cannabis. We use this figure to calibrate a cost function that matches our two assumptions: 1) cost at size 32,670, excluding the LCB license (which has no counterpart in the floriculture industry upon which estimation Schumacher and Marsh' (2003) estimate is based) is as found from the calculations above, and 2) elasticity is 0.913 everywhere across the range of scales we consider. We thus assume that the cost function can be well approximated by an isoelastic cost function passing through the quantity and cost estimated for our typical greenhouse. We then add the LCB license fee and cost of security monitoring on top of the estimated cost curve.

The cost function (i.e., all cost except the LCB license) can be approximated by a simple power function, and is of form

$$C(Q) = aQ^b$$

where Q is quantity (here taken to be greenhouse space—since by assumption we take actual production quantity to be proportional to greenhouse space, this choice is immaterial for purposes of calibrating the cost function) and (a,b) is a pair of unknown parameters. Assume that cost is known to be C_0 at Q_0 and that elasticity is known to be ε_0

at Q_0. The two assumptions give rise to a pair of equations that we can solve for the two unknowns a and b. The first equation, $C(Q_0) = C_0$, implies:

$$C_0 = aQ_0^b$$

Economists calculate cost elasticity as:

$$\varepsilon(Q) = C'(Q) \frac{Q}{C(Q)}$$

Where the first term on the right hand side is the derivative of the cost function. So the second equation for the elasticity at Q_0 is:

$$\varepsilon_0 = b$$

That is, for our chosen form for the cost function (known as an *isoelastic* function), elasticity is constant, which makes it particularly convenient for our calculations. Plugging in elasticity for b into the first equation above and solving for a yields:

$$a = C_0 Q_0^{-\varepsilon_0}$$

To calculate the total long run variable cost for any other quantity, Q, the following formula is used:

$$C(Q) = C_0 Q_0^{-\varepsilon_0} Q^{\varepsilon_0} = C_0 \left(\frac{Q}{Q_0} \right)^{\varepsilon_0}$$

Plugging our elasticity estimate and Q_0 = 32,670 (our typical size greenhouse) into this last equation yields this annual cost equation (where we have also added in the license and security monitoring cost):

$$C(Q) = 1000 + C_0 \left(\frac{Q}{32670} \right)^{-0.91335}$$

Given any particular value of C_0, which varies with the horizon of the scenario, the long run average cost function (LRAC) can then be calculated by dividing $C(Q)$ by quantity.


Estimated cost function

With the assumptions and calculations of the previous section now in hand, we can present our estimated cost functions for growing cannabis. For each type of growing we present the cost curves for several time horizons. Economies of scale are exhibited when average cost functions are decreasing with quantity (or facility size, in our application). There the shape of the LRAC functions we present are of particular interest.

Cost functions for indoor growing

The LRAC functions we compute are depicted in Figure 2 and Figure 3 for indoor growing of cannabis. The horizontal axis is the total size of the facility, including non-production space. We calculated LRAC for indoor facilities ranging from 1,000 to 15,000 sf. We could just as well have plotted the LRAC curves against production space or sf of canopy, but that would only change the horizontal scale without affecting the shape of the curve. The left vertical axis measures annualized LRAC per pound of production, and the right axis measures the same in grams.

Figure 2: Indoor LRAC Curve, One-Year Scenario
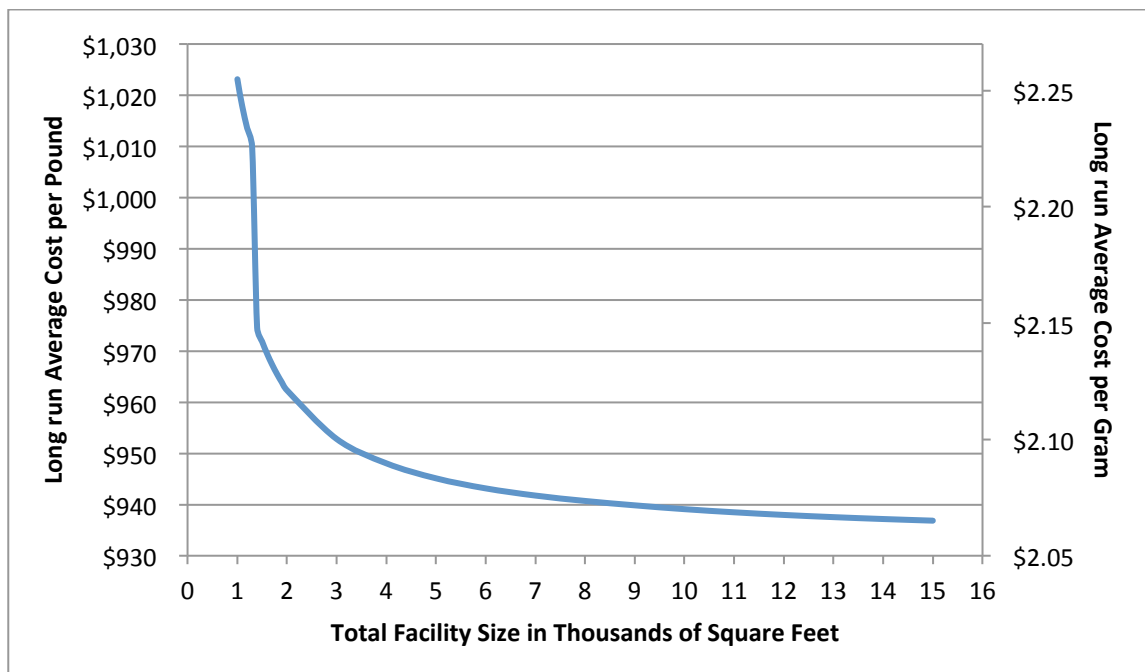
The LRAC function for indoor growing of cannabis with a one-year horizon is in Figure 2. With such a short horizon, average costs are the largest among all the scenarios we consider, because there is so little time over which to amortize the sunk costs of capital and equipment. LRAC ranges from a high of $1,023/pound ($2.26/gram) per annum for the smallest (1,000 sf) facility to a low of $937/pound ($2.07/gram) for the largest (15,000 sf) facility. LRAC is decreasing everywhere, implying that overall, there are mild economies of scale. Taking discrete change from a 1,000 sf facility to a 15,000 sf facility, the implied elasticity of cost with respect to quantity[50] is 0.910, strikingly close to the

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[50] The formula for the cost elasticity from a discrete change in quantity is %Δ (Total Cost)/%ΔQuantity.

figure of 0.913 that we assume without such detailed information for the greenhouse scenario.[51]

The most striking feature of the cost curve is the large decline in average cost once the threshold of 1,350 sf is passed and the enterprise can take advantage of the more favorable electricity tariff. Beyond that size threshold, further economies of scale come from the other cost aspects discussed above (most notably, the long run fixed costs, the permitting, and certain construction items as detailed in section V.B.2).

The LRAC curves for the three, five, 10, and 30-year scenarios are in Figure 3. Each has basically the same shape as the shorter horizon scenario, but of course the level of average cost for any quantity decreases as the horizon increases, up to the least common multiple of the various capital and equipment lives (30 years).

The horizon chosen makes quite a difference in the level of cost. For example, a 1,500 sf facility has annualized average cost per pound of $972 with a one-year horizon, $639 with a three-year horizon, $580 with a five-year horizon, $534 with a ten-year horizon, and $518 with a 30-year horizon. These declines in cost with the longer horizons are far greater than the cost decreases stemming from economies of scale within any one horizon.

The final curve in the figure, for the 30-year scenario, represents minimized LRAC.[52] At the larger facility sizes, costs converge to about $513 per pound ($1.13/gram). The level of the 30-year LRAC curve is about 54% that of the one-year scenario. Our analysis thus reveals one reason why prices so high in the cannabis industry. Expected LRAC is the average of the LRAC curves, where the weights in the averaging are the probabilities that each scenario is the relevant one. When enforcement risk is large, there is a greater chance of ending up with one of the shorter horizons, and that leads to higher costs (and therefore prices). And this consideration applies even before marking up costs even further to account for risk aversion.

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[51] We did not choose our greenhouse cost elasticity estimate to make it conform to this result; we settled on the midpoint formula for the assumed cost elasticity before we made this calculation.

[52] Extending the horizon beyond 30 years increases LRAC (unless the horizon is a multiple of 30), because any other horizon leaves some capital unused (i.e., not fully physically depreciated) at the terminal period.

Figure 3: Indoor LRAC Curves, Three- to 30-Year Scenarios
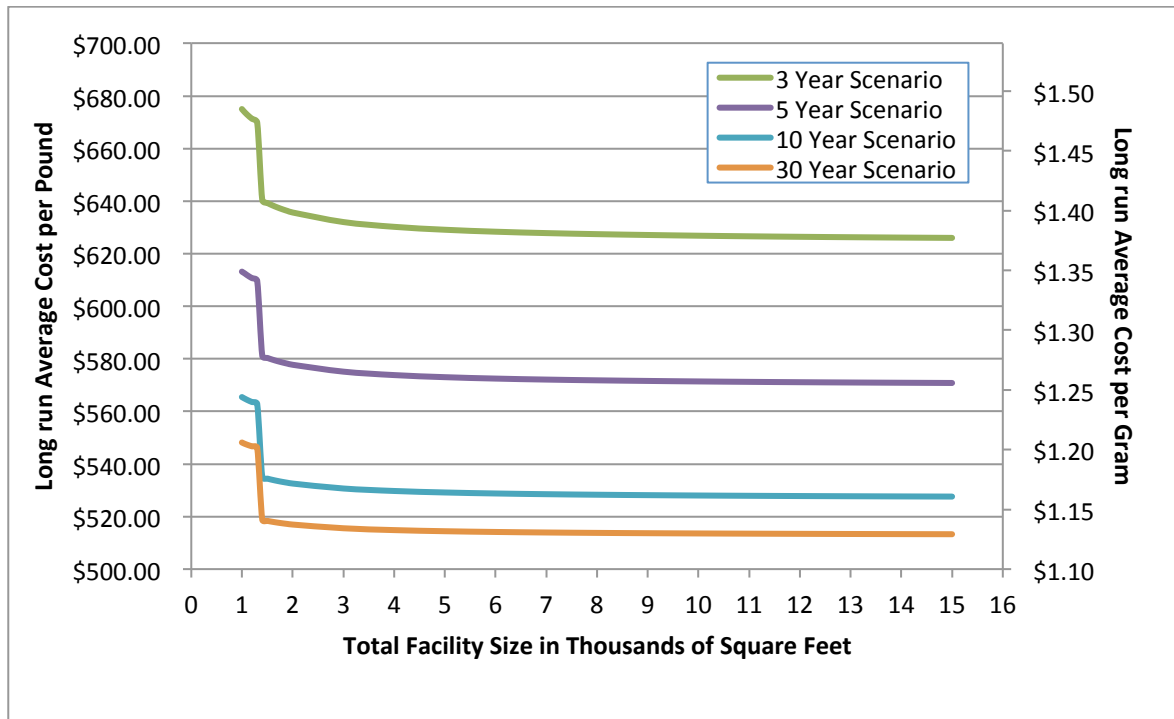
Cost functions for greenhouse growing

The LRAC functions for growing cannabis in greenhouses are all in Figure 4. Here we consider a scale range from 5,000 to 100,000 sf. Except for the smallest greenhouses in the longer horizons, where our approximation error involved in the isoelastic cost function estimation is greatest, production costs are lower than for the indoor scenario, as expected. Our assumption that cost is isoelastic ensures that each curve has a "textbook smooth" shape. In the one-year scenario, annualized LRAC ranges from $681 to $584 per pound. In the 10 year scenario, which is the minimum long run cost horizon for this case, annualized LRAC ranges from $565 to $434.

Figure 4: Greenhouse LRAC Curves, One- to 10-Year Scenarios
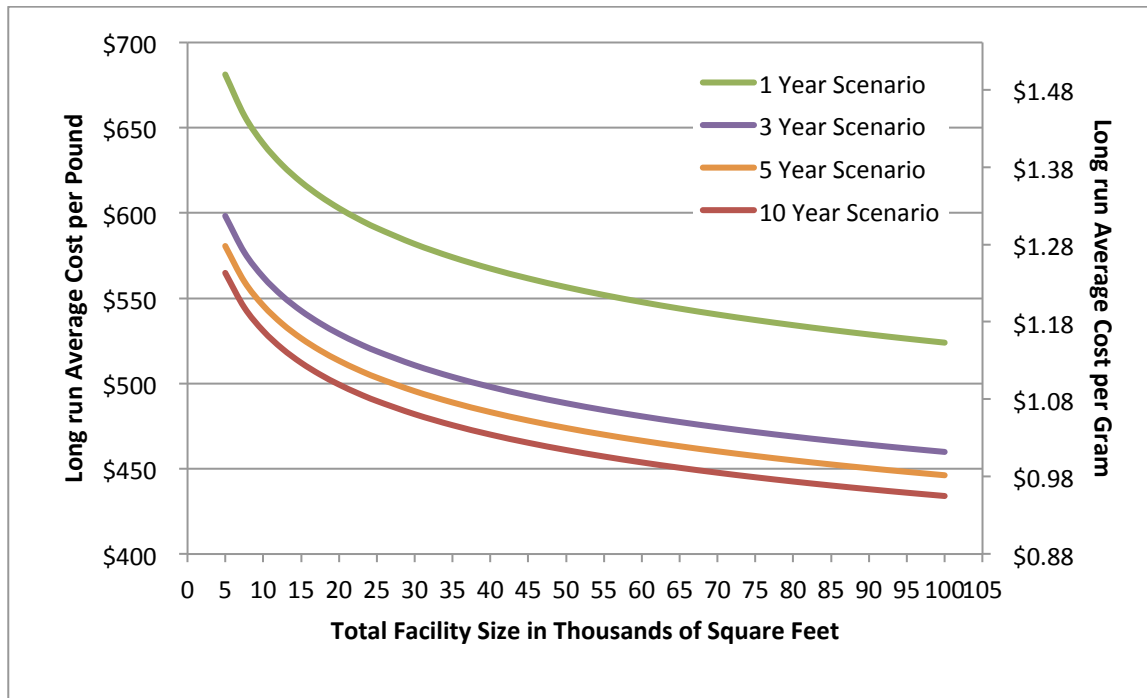
Comparison of cost functions for indoor and greenhouse growing

To facilitate comparison of indoor and greenhouse growing, Figure 5 shows the LRAC curves for indoor and greenhouse production in the one-year horizon, and shows that greenhouse growing enjoys a significant cost advantage.

Figure 6 shows that in the five-year horizon, the relative advantage of greenhouse growing is not as large as in the one-year scenario. It is the greater capital costs of indoor construction that create a large part of the cost disadvantage of indoor growing, and that factor shows up the more acutely the shorter the horizon (differences in energy costs are an important part of the remaining difference.

Figure 7, we plot the cost curves already presented together on the same graph

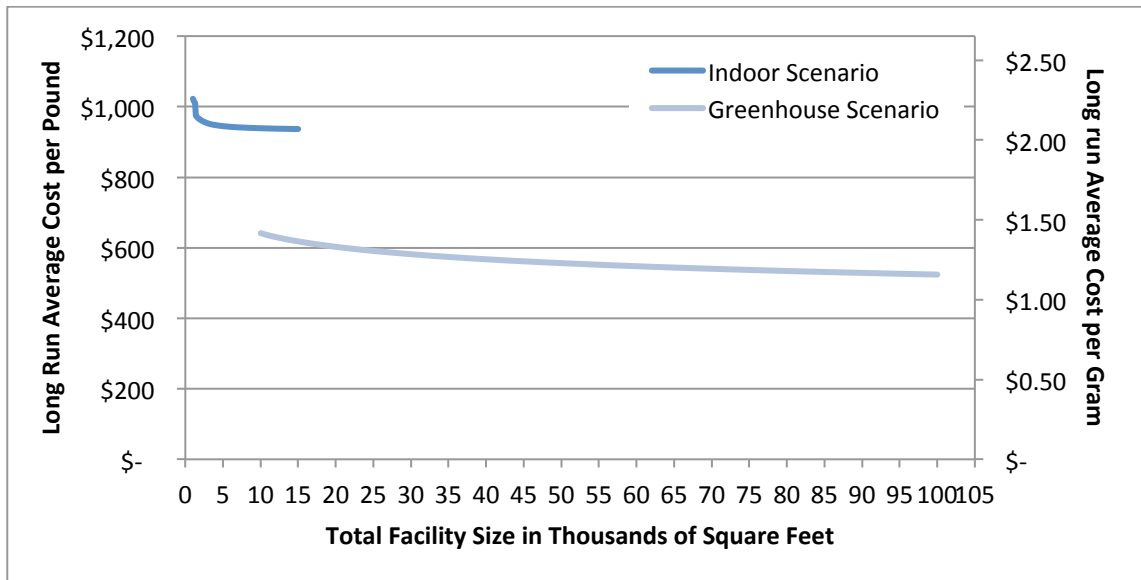**Figure 5: Indoor vs. Greenhouse LRAC Curves, One-Year Scenario**

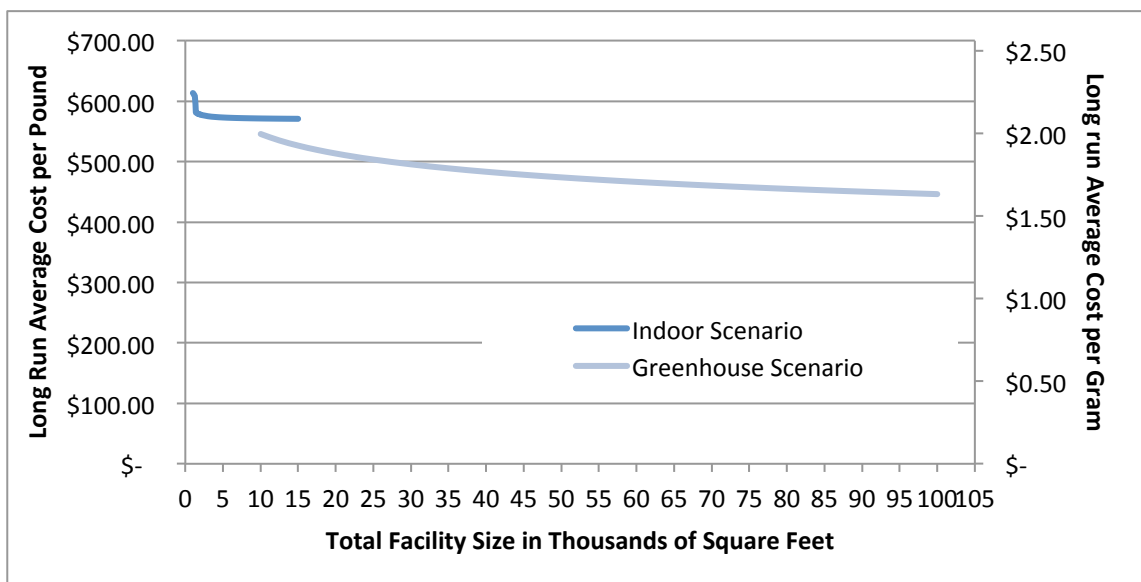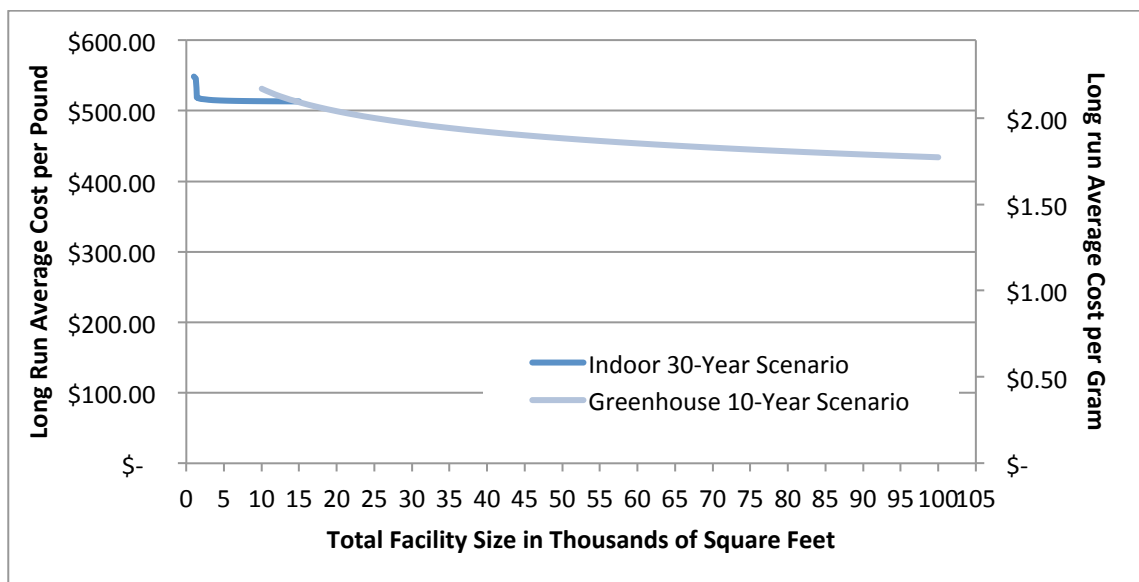**Figure 6: Indoor vs. Greenhouse LRAC Curves, Five-Year Scenario**

Figure 7: Indoor vs. Greenhouse LRAC Curves, Minimum-Cost Scenario

Implications for the LCB

Our estimates suggest that the economies of scale for the indoor production of marijuana are modest. The economies of scale for greenhouse growing are larger than for indoor growing, but even these are relatively mild. This conclusion was reinforced in the perspectives we solicited from growers responding to our cost-of-production survey. The growers surveyed were of the opinion that there would be some unit cost advantages to increasing the size of their operations (in particular they referenced quantity discounts on inputs), but that the gains would not be substantial. Only one-third of the respondents were of the opinion that they would enjoy substantial reductions in costs if they were to substantially increase the scale of their operations.

These estimates provide only a limited understanding of likely economies of scale in response to legalization of commercial production, as they focus on technologies currently available and cover only a limited span of sizes of growing operations. Our interviews with large growers lead us to conclude that the economies of scale for large outdoors grows (multi-million dollar operations) might be substantial and would follow largely from the professionalization of the production processes. While cost reductions in the 1,000 to 50,000 square feet range might be modest, a price drop anticipated for larger producers might be substantial. Legalization will likely lead to significant innovation in marijuana growing technology as the newly legalized market seeks new ways to lower costs and increase profitability. The technological revolution and improvements in professional production management following legalization will disproportionately benefit larger-scale producers as only larger outfits would be able to invest in the

technology and expertise needed for professional process management. As operations professionalize, security costs (which were factored in here at only $45 per month, regardless of scale) would likely increase. As the size of the operations increase, and as more-expensive technology is deployed, the security risks might be higher, entailing greater security monitoring costs. On the other hand, we are also more likely to see security services tailored to cannabis production made available, and active competition in the provision of such services may keep costs moderate. Nevertheless, as this security market develops we might see an increase in spending on security.

Many existing growers in Washington State face barriers to significantly expanding their operations. Our survey of growers reveals a surprisingly high cost of money. Our respondents reported an average effective annual interest rate of 32%, which reflects a significant risk premium. Many of the growers we interviewed regarded access to formal banking services to be a major setback to their efforts to expand operations. A further barrier is the ongoing risk of federal enforcement (which is reflected in the interest risk premium). Given that the costs of expanding operations are heavily front-loaded, a longer production time horizon affords growers a longer period to amortize costs and recoup their upfront investment. Attitudes regarding the benefits of expanding operations are strongly influenced by growers' perceptions regarding the likelihood of the federal government seizing their assets.

Our economies of scale analysis is limited to indoor and greenhouse grows (when we produced our estimates WLCB was not considering allowing outdoor growing). As outdoor growing is now a live possibility, an important next step is to develop cost estimates specific to outdoor growing. This would require interviews targeting outdoor growers (of various sizes). A detailed analysis of costs of existing outdoor growers should be supplemented with the econometric literature on nearest-neighbor crops, to provide some perspective on how costs might change for a mature industry where technological innovations have been realized.

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Table V.1: Indoor Cannabis Production: Capital Cost

	Wage	Markup	1,500 sf Facility		10,000 sf Facility	
			Hours	Initial Value of Capital	Hours	Initial Value of Capital
Construction						
Labor						
Design	$27.64	200%	12.00	$663	80.00	$4,422
General contracting	$53.77	200%	77.65	$8,350	517.65	$55,668
Electrician	$29.59	200%	70.00	$4,143	150.00	$8,877
Plumber	$28.71	200%	60.00	$3,445	400.00	$22,968
Skilled carpenter	$23.32	200%	50.00	$2,332	350.00	$16,324
HVAC professional	$25.74	200%	50.00	$2,574	80.00	$4,118
Security system installer	$23.14	200%	5.00	$231	40.00	$1,851
Permitting				$823		$2,672
Subtotal construction				*$22,562*		*$116,901*
Equipment						
Cultivation				$12,741		$84,939
Environmental				$26,214		$174,760
Lighting				$32,935		$219,567
Nutrient delivery				$2,611		$17,405
Finishing				$942		$6,281
Subtotal equipment				*$75,443*		*$502,952*
Genetic Stock						
Plants and rooted clones				$4,500		$30,000
Total Initial Value of Capital				$102,505		$649,853
Startup cost per sf				$68.34		$64.99

Table V.2: Indoor Cannabis Production: Long Run and Short Run Variable Costs, per annum

	Wage	Markup	1,500 sf Facility		10,000 sf Facility	
			Hours	Economic Cost	Hours	Economic Cost
Long Run Variable Costs						
Labor						
Management	$41.79	130%	223	$12,107	1,486	$80,714
Janitorial	$13.12	130%	54	$914	357	$6,091
Rent-related Cost						
Rent				$8,280		$55,200
Last month rent + security deposit (opportunity cost)				$138		$920
Insurance				$494		$3,456
Subtotal LRVC				$21,933		$146,382
LRVC per sf				$14.62		$14.64
Short Run Variable Costs						
Labor						
General agricultural worker	$10.60	130%	223		1,486	$20,473
Trimming	$10.60	130%	2,360	$32,521	15,733	$216,805
Non-labor inputs						
Electricity				$28,553		$190,355
Water				$480		$3,200
Soil				$8,303		$55,353
CO_2				$2,631		$17,540
Nutrients				$5,090		$33,933
Pesticide				$2,400		$16,000
Subtotal SRVC				$83,049		$553,660
SRVC per sf				$55.37		$55.37

Notes: Trimming wage bill is for years after the first. First year trimming wage bill is only 5/6 as much, since there is no harvest in first two months.

Table V.3: Greenhouse Cannabis Production: Costs for a Typical Operation

Capital Costs	Assumption	34,640 sf Facility *Total Cost*
Construction	$10/sf of greenhouse space	$326,700
Equipment	$10/sf of greenhouse space	$326,700
Genetic stock	0.0635 plants/sf of growing space	$24,503
Total initial value of capital		$677,903
Startup cost per sf		$20.75
Long Run Variable Costs		*Cost Per Annum*
Management Labor	196 hours/month; same wage and markup as for indoor scenario	$127,790
Rent-related Cost		
Rent	$566/month	$6,792
Last month rent + security deposit (opportunity cost)	Security deposit is equal to one month's rent	$113
Insurance	$0.33/sf of greenhouse space p.a.	$10,781
Subtotal LRVC		$145,476
LRVC per sf		$4.20
Short Run Variable Costs		
Labor		
General agricultural worker	202 hr/month; same wage and markup as for indoor scenario	$33,443
Trimming	Trim rate = 41.42 g/hr; same wage and markup as for indoor scenario	$456,386
Non-labor inputs		
Electricity	Needs 25% as much as indoor; price = $0.0596/kWh	$222,108
Soil	Same amount needed/sf canopy as indoors	$221,436
Water	9/16 × same amount needed per sf canopy as indoors	$12,801
CO_2	"	$70,167
Nutrients	"	$135,747
Pesticide	"	$64,007
Subtotal SRVC		$1,216,095
SRVC per sf		$35.11
Long Run Fixed Costs		
LCB license	$1000 p.a. renewable	$1,000
Security monitoring	Same as for indoor scenario	$540

Marijuana Cultivator's Cost of Operations Survey

Thank you for agreeing to participate in our research!

We are interested in your responses to questions about the cost of cultivating marijuana, and your perceptions regarding how cultivation costs differ based on the size of operations. Your experience will help our understanding of the economics of marijuana production. Responses will be kept confidential.

First we would like to ask you a few questions about your operations. If you are involved with more than one operation, please describe only one operation (the one you consider to be the most significant) for the cost estimates that follow.

1. Which response best describes the type of cultivation?

☐ Indoor with artificial lighting

☐ Greenhouse with supplemental artificial lighting

☐ Greenhouse without supplemental artificial lighting

☐ Outdoors

Other (please specify) nature of operation

[   ]

2. If you grow outside, please report in square feet (leave blank if you do not grow outside):

The total area of the land used in the operation (including: storage, compost, buildings, etc.)   [   ]

The area under cultivation (that is, the canopy)   [   ]

3. If you grow inside, please report in square feet (leave blank if you do not grow inside):

The size, in square feet, of all production buildings (excluding, when possible, any rooms or area that is spare space not currently used).   [   ]

The area used for growing (include mother plants and seedlings; exclude walkways and halls, to the extent possible)   [   ]

4. In a typical year, how many times would you harvest?

....times per year   [   ]

5. How many marijuana plants per harvest did you harvest last year?

Number cultivated   [   ]

6. How many pounds of saleable marijuana did you produce in the last year?

Saleable pounds   [   ]

7. Of that saleable marijuana, how much was trim/shake?

Pounds   [   ]

8. Which state is your operation in (we use this to adjust costs that vary by state)?

[   ]

Marijuana Cultivator's Cost of Operations Survey

"Start up" costs for site preparation

Now we would like to ask you a few questions related to your costs of production. Please note, here we are interested only in the costs related to cultivation and processing of marijuana; we are NOT interested in wholesale or retail costs.

If you are involved with more than one operation, please describe only the most significant for the cost estimates that follow.

We'll start by asking you questions related to "start up" costs. Answer as if you were starting up in 2013 (assigning values at current prices makes it easier for us to compare costs).

9. What is your "cost of money" (as a percent, %)? This can be your interest rate on business loans or another figure that you use for your planning purposes when considering investing in marijuana cultivation.

%

10. Provide your best estimate of the construction costs (dollar amount) for preparing the physical space (design, general contracting, electrical, plumbing, carpentry, HVAC installation, and any other site preparation costs).

Estimated total construction cost ($)

11. Please indicate the major items you included when providing your construction cost estimate above.

"start up" equipment costs

We are now going to ask you questions related to the equipment costs you incurred when starting up. Answer as if you were starting up in 2013 (assigning values at current prices makes it easier for us to compare costs).

12. For each of the following please provide your best estimate of the "start up" costs you incurred (in dollars, $)

Cultivation and nutrient delivery (e.g., pots, trays, stands, watering equipment, pumps)

Environmental (e.g., air conditioners/heaters, air filters, all other HVAC equipment)

Lighting (e.g., lamps, timers, electronic ballast; do not include cost of electricity)

Structure (e.g., if greenhouse new construction)

Other

13. Please indicate the major items you included when providing your cultivation and nutrient delivery cost estimate above.

14. Please indicate the major items you included when providing your environmental equipment cost estimate above.

15. Please indicate the major items you included when providing your lighting equipment cost estimate above.

16. Please indicate the major items you included when providing your structure equipment cost estimate above.

17. Provide your best estimate of the start up costs (dollar amount) of buying plant stock (seed, rooted clones, other) for a start up that is similar to your operation in size.

$

Labor costs

Now we are going to ask you about your labor costs for the past year. If you incur these costs monthly, please multiply by 12 to arrive at an annual estimate.

18. Please provide your best estimate of the total labor costs incurred by your operation in the past year (total labor costs for a 12 month period, including cost of management salaries and hourly wage labor, and including any benefits paid).

12-month labor cost ($)

19. How many laborers (earning hourly wages, excluding salaried employees) did your operation typically employ at any one time in the past 12 months?

Average number of hourly wage earners

20. On average, how many hours did a laborer work per week?

Number of hours worked

21. How many full-time equivalent salaried employees (excluding hourly laborers) did *this operation* typically employ at any one time in the past 12 months?

Average number of hourly wage earners

22. Provide your best estimate of the typical earnings of the following employees (excluding any benefits paid):

Hourly wage workers (please provide typical hourly wage paid)

Salaried employees (please provide typical monthly salary)

23. Do you ever supplement salaries or wages with in-kind payments in product (marijuana)?

○ Yes

○ No

24. Provide your best estimate of the total market value of the in-kind payments given as product (provide estimate over a 12 month period).

Total market value of product given as payment "in-kind" (in dollars)

Other recurring costs

Now we are going to ask you about your annual non-labor recurring costs for the past year. If you incur these costs monthly, please multiply by 12 to arrive at an annual estimate.

25. Provide your best estimate of the recurring costs below

Electricity

Other non-labor inputs (water, soil, fertilizer, nutrients, CO_2)

Rent for structure and/or land

Taxes, insurance, repair costs for the equipment

26. Are there any other significant recurring costs we have not mentioned here? If yes, please provide a brief description and indicate the cost incurred over the last year.

Costs and Scale of Production

Now we are going to ask you a few questions about how costs vary with the scale (size) of production.

27. Think about a grower cultivating an area ten times as large as your current operation. What factors would contribute the most toward making this grower's average costs lower than yours, if any? List a few factors.

28. Think about a very small grower – say, one-half to one-tenth as large as your current operations. What factors would contribute the most toward making this grower's average costs higher than yours, if any? List a few factors.

29. How would your average costs (per pound of marijuana produced) vary if you changed the size of your operation? Compared with your costs of operation described above, how do you think your costs *per pound of marijuana produced* would differ for operations of the following sizes? (please use the pull-down menus to show cost reductions or cost increases).
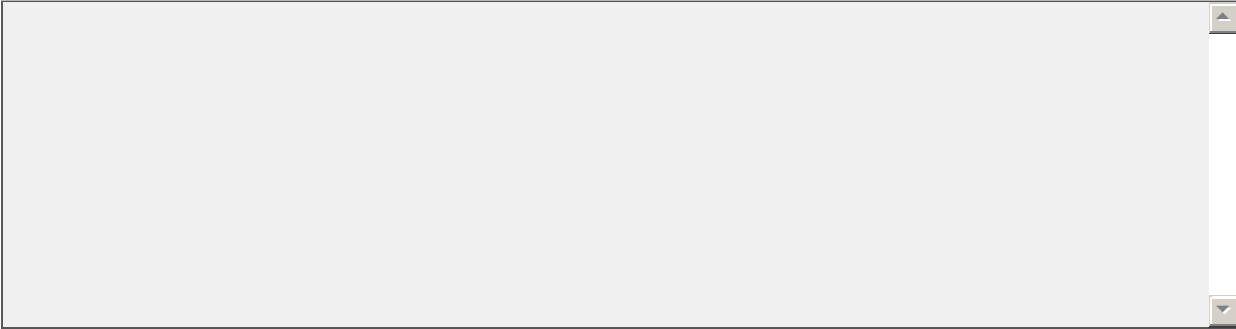
	Smallest (operation one-tenth your size)	Smaller (operation one-half your size)	Larger (operation twice your size)	Largest (operation ten times your size)
Construction costs				
Equipment costs				
Recurring Costs				
Labor costs (per person)				

30. Would you expect to receive quantity discounts on any of your inputs if you scaled up your operation?

○ Yes

○ No

31. Which inputs and about what size discount?

32. Think for the moment about your type of growing operation (e.g. indoor, greenhouse, outdoor), and think only about the cost side of production. To make production cost per pound of marijuana as low as possible, the best size operation would be...

○ About our current size

○ Larger than our current size, but not too big

○ As large as possible

○ Smaller than our current size.

○ It doesn't matter; costs per pound are about the same regardless of size

33. Roughly what size (in square feet) would minimize your costs?

Size (in square feet)

Wrap up questions

A few wrap-up questions, and then you are done!

Marijuana Cultivator's Cost of Operations Survey

34. Can you think of important issues related to cost of production (especially how costs change in relation to the size of an operation) that we did not ask in this survey? If so, please describe what we missed.

35. Do you think production costs would differ substantially in states where *commercial* growing of marijuana is legal, compared with states where it is illegal? Would operating in a "legal" state make operation costs more or less expensive? Please describe which costs you think would change (in which direction) and why?

All done!

Thank you for completing our survey. We appreciate the opportunity to learn from you.