WASHINGTON STATE UNIVERSITY

School of Economic Sciences

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Assessing the Impact of Labor Shortages as a Marketing Barrier

Executive Summary

Labor is an important input into the production and distribution of U.S horticultural commodities and products. Though labor is necessary throughout the production of horticultural commodities, it is also a critical input to successful marketing and delivery. Historically, labor shortages are usually thought of as a pre-harvest problem, and the economic impacts of labor shortages are estimated from models related to production. Thus the size and economic consequences of post-harvest labor shortages are unknown.

The research from this project yielded an estimate of the forgone economic welfare due to post-harvest labor shortages in marketing, distribution, and delivery. We focused on the U.S. pome (apple) and prunus (peach) industries because of their large total value of production and their wide geographic spread. Therefore, our findings apply to multiple states, producers, and agribusinesses as well as being illustrative of the problem to the greater agricultural sector.

We estimate that given plausible shocks of an increase in final demand and a decrease in unskilled labor supply, wages of skilled and unskilled labor would need to increase by 2.8% and 6.4% for the markets to clear. When we fix wages at the pre-shock level, it creates labor shortages estimated to be 35% of the pre-shock level of employment for unskilled labor and 2.2% for skilled labor. Prices increase by slightly more than 11% for both pome and prunus compared to the post-shock competitive equilibrium. Output decreases by 5.6% for pome and 13.1% for prunus.

When we include commodity-specific spoilage rates to explicitly consider the impact of a labor shortage on the transportation network, we find that though both the pome and prunus industry suffer losses, the prunus industry, which has the quicker spoilage rate, is severely impacted. Prunus output decreases by 44.9% and price increases by 37.6% compared to the post-shock competitive equilibrium whereas pome output decreases by 1.7% with price increasing 10.4%. Thus a labor shortage in the transportation sector harms some industries more than others. However, inclusion of the transportation network yielded results showing that producers for both the pome and prunus industries are harmed by the labor shortage instead of gaining as in the case without the transportation network. The pome industry suffers an economics surplus loss of 8.4% of the pre-shock revenue. The prunus industry suffers an economic surplus loss of 32.4% of the pre-shock revenue.

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Assessing the Impact of Labor Shortages as a Marketing Barrier

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Outline of the Issue or Problem

Labor is an important input into the production and distribution of U.S horticultural commodities and products. Though labor is necessary throughout the production of horticultural commodities, it is also a critical input to successful marketing and delivery. Historically, labor shortages are usually thought of as a pre-harvest problem, and the economic impacts of labor shortages are estimated from models related to production. Thus the size and economic consequences of post-harvest labor shortages are unknown. This is an important marketing problem because post-harvest labor shortages undermine the best methods for processing, packing, handling, transporting, storing, distributing, and delivering agricultural products.

The objective of the project is to estimate the forgone economic welfare due to post-harvest labor shortages in marketing, distribution, and delivery. We focus on the U.S. pome (apple) and prunus (peach) industries because of their large total value of production and their wide geographic spread. Therefore, our findings apply to multiple states, producers, and agribusinesses as well as being illustrative of the problem to the greater agricultural sector. Achieving our objective is a necessary step to eliminating artificial labor barriers to the free movement of agricultural products in commercial channels, as well as the reduction of a barrier limiting industry growth.

Description of How the Issue Was Approached and Objectives

The overall *goal* of the research agenda is to reduce the artificial barriers for efficiently and profitably processing, preparing for market, packing, handling, transporting, storing, distributing, and marketing agricultural products preventing their free movement in commercial channels; and to assist in the development of more efficient and orderly methods for marketing, distribution, and delivery. As a step towards obtaining this overall goal, the *aim* of this research project is to estimate the profit and welfare losses associated with post-harvest labor shortages in the U.S. pome and prunus industries to assess if these shortages are causing a large and inefficient distortion of resources preventing the free, uniform, and consistent delivery of commodities and products expected by domestic and foreign consumers. We are pleased to report that this aim has been ***achieved.***

Objective 1: Estimate the current wage for skilled and unskilled labor during the post-harvest period. **Completed.**

Objective 2: By explicitly accounting for activity along the post-harvest supply, distribution, and delivery chain, construct regional and national models of the following *industries: apple, pear, cherry, peach and nectarine, plum and prune, and apricot.* **Completed using national data and models for apples and peaches only.** The need for these model changes was discussed in the first and second status report. The third status report discussed our improvement in method from two separate industry models to a single integrated two-industry model.

Objective 3: Estimate the post-harvest labor shortage for each industry, and the welfare loss from the labor shortage. **Completed.**

Objective 4: Estimate the wage needed to eliminate or substantially reduce post-harvest labor shortages. **Completed.**

To achieve our aim and objectives, we constructed an equilibrium displacement model that has two related, but separate, industries (pome and prunus) and two resource inputs (unskilled labor and skilled labor). That we were able to build a model where the outputs are interrelated is an improvement over the method we proposed in the grant application (a separate model for each industry). We maintained the ability to estimate industry-specific results as proposed, but gained accuracy.

We obtained data on employment and wages by agricultural occupations and partitioned that data into those tasks considered to require unskilled labor and those that require skill-labor. The skilled-labor tasks were largely post-harvest occupations such as marketing, and transporting and delivery. This accomplished objective 1.

We obtained data on commodity prices and quantities to establish a benchmark. After first applying the benchmark levels to the model, we were able to estimate what would happen if there was a simultaneous increase in output demand and a decrease in the supply of unskilled labor, as predicted in the literature. To determine the size of industry welfare loss from labor shortages (objective 3) and the size of the wage increase to eliminate those shortages (objective 4), we compared the impacts of those two shocks from the new competitive equilibrium to the case where wages were fixed at pre-shock levels. We repeated that comparison when the transportation sector was, and was not, included, achieving objective 2.

<u>Description of the Contribution of Public or Private Agency Partners</u>

Our proposal featured co-authors from diverse interests (regional development, agriculture, transportation) within the School of Economic Science at Washington State University. Though no other public or private agencies were direct partners, our work was made possible by state funds, the provision of a Ph.D. student, and the financial support of Agricultural Research Center project #0540 at WSU.

Summary of Results, Conclusions, and Lessons Learned

Our modeling focus is designed to estimate how the downward shift of unskilled labor supply affects producers' demand for skilled post-harvest labor such as those in the managing, marketing and distribution occupations. We explicitly consider and model the spoilage rate along the transportation network in order to get a better estimate for the deadweight loss associated with a labor shortage that may differ among commodities that spoil at different rates.

We estimate that given the plausible shocks of a 5.4% increase in final demand and a 7.0% decrease in unskilled labor supply, wages of skilled and unskilled labor would need to increase by 2.8% and 6.4% for the markets to clear. When we fix wages at the pre-shock level, it creates labor shortages estimated to be 35% of the pre-shock level of employment for unskilled labor and 2.2% for skilled labor. Prices increase by slightly more than 11% for both pome and prunus compared to the post-shock competitive equilibrium and output decreases by 5.6% for pome and 13.1% for prunus. Yet despite the inefficiency in the economy from the labor shortage, producers' welfare increases relative to the competitive outcome because the labor-shortage-induced decrease in output is more than made up for by the increased prices obtained by sellers as well as the surplus obtained from paying a lower than competitive wage in both labor markets.

When we include commodity-specific spoilage rates to explicitly consider the impact of a labor shortage on the transportation network, we find that though both the pome and prunus industry suffer losses, the prunus industry, which has the faster spoilage rate, is severely impacted. Prunus output decreases by 44.9% and price increases by 37.6% compared to the post-shock competitive equilibrium whereas pome output decreases by 1.7% with price increasing 10.4%. Thus a labor shortage in the transportation sector harms some industries more than others. However, inclusion of the transportation network yields results showing that producers for both the pome and prunus industries are harmed by the labor shortage instead of gaining as in the case without the transportation network. The pome industry suffers an economics surplus loss of 8.4% of the pre-shock revenue. The prunus industry suffers an economic surplus loss of 32.4% of the pre-shock revenue.

The conclusions are that predicted simultaneous demand and supply shocks along with wage rigidities create sizeable labor shortages whose affects spill over to post-harvest activities such as transportation and marketing. These affects are quite large relative to the size of the pre-shock industries, though the larger, more price inelastic, and less time-sensitive pome industry is able to handle the shocks more easily than the prunus industry. Eliminating the inefficiency in the labor markets yields more output at competitive prices, which creates many millions more in economic surplus and welfare.

From the research perspective, one lesson learned is the crucial importance of explicitly considering post-harvest activities such as transportation in modeling agricultural markets. Our results estimated that producers benefit from the labor shortages if transportation is not considered. That result is very different, and has very different policy implications and ramifications, from when transportation is modeled. A second lesson learned is that modeling commodity-specific characteristics is important.

The difference in characteristics between the pome and prunus industries yields greatly different abilities for each industry to respond to the shocks in the model.

Discussion of Current or Future Benefits Derived from the Project

Our project fits into the following categories from the USDA-AMS call for proposals: 1. food, 2. horticulture, and 3. manufactured products derived from these commodities. The project is focused on the following marketing issues: 1. addressing barriers, 2. determining the best methods for processing, preparing for market, packing, handling, transporting, sorting, distributing, and marketing agricultural products, 3. assisting in the development of more efficient marketing methods, practices, and facilities to bring about more efficient and orderly marketing, and reduce the price spread between the producer and consumer, and 4. eliminating artificial barriers to the free movement of agricultural products in commercial channels. Thus we aim for our impact to be in recovering lost profits and producer and consumer welfare by describing the extent of the problem to stakeholder groups and fellow professionals.

The direct current and future benefits derive from the dissemination of the project results to our stakeholder supporters. Those benefits are described in detail below. We expect and hope the benefits derived from this project via our peers comes from our results showing how incredibly important the explicit consideration of the transportation network post-harvest is to outcomes and welfare calculations. Our welfare estimates for producers experience a tremendous change from a net positive to a large negative when transportation is considered. Furthermore, the outcomes of the two industries react differently. Thus we see a major impact from our work on our academic peers to be the importance of considering post-harvest activity and transportation in models where end sales are important.

Recommendations for Future Research and an Outline of Next Steps

Our model estimated the static implications for welfare loss from post-harvest labor shortages. Thus a promising area for future research is to add a time component to the model. This would allow for the entry of foreign imports in response to the domestic price premium caused by the labor shortage. Estimates on welfare loss from the dynamic model will no doubt be larger. The question is how much larger. In addition, a future dynamic model would allow for the very important issue of reputation effects to be considered. That is, our current estimates do not reflect the marketing impact from quality loss due to delays along the transportation network that could lead consumers to switch to imports from other countries or entirely different food products. Our model could also be extended to other industries, but we believe that is a lesser priority than adding the time dimension.

Description of Project Beneficiaries

Our estimates for welfare loss were estimated using data from the pome and prunus industries. Thus the direct beneficiaries include the producers and commodity associations of those products. As promised in our grant proposal, we were able to successfully estimate the increase in wage needed to eliminate labor shortages. This result is immediately useful to the industry. The letters of support from commodity associations (Washington Apple Commission and Pear Bureau Northwest) included as part of our grant application show the interest and support from these direct beneficiaries. Other immediate beneficiaries include the transportation industry that can point to our results as an indication of the economic importance of their service, and consumers of pomes and prunus who benefit from the greater output and lower price when there are no post-harvest labor shortages.

We chose the pome and prunus industries in part because of their size and geographic spread. Thus not only does our work directly benefit producers of pome and prunus nation-wide, our results are likely qualitatively correct for other agricultural commodities and those other industries can benefit from the lessons of the harms of post-harvest labor shortages. Finally, marketers of agricultural products benefit from our research as it is the first to explicitly consider and estimate the importance of post-harvest occupations such as marketing and delivery.

Additional Information Generated by the Project

In addition to the report generated by out project, we have also created an executive summary of the results to be used to disseminate the findings to industry stakeholders. Furthermore we have done, or plan to do, the following informational releases:

Given and Planned Presentations:

1. 49th Annual Pacific Northwest Regional Economic Conference, Bellingham WA, Apr. 22-24, 2015.
2. The Pennsylvania State University, Department of Agricultural Economics, Sociology, and Education, Oct. 2, 2015.
3. Washington State University, School of Economic Sciences, Dec. 11, 2015.

Planned Publication Submissions:

4. "Assessing Post-Harvest Labor Shortages, Wages, and Welfare" to be submitted to *Applied Economics Perspectives & Policy.*
5. "Welfare Losses from Post-Harvest Labor Shortages in the Pome and Prunus Industries" to be submitted to Washington State University Extension Publishing.

Planned Online Material:

6. Publicly-released material will be made available electronically on the Extension website of Dr. Andrew Cassey, http://ses.wsu.edu/extension/regional_economics/.
7. Dr. Cassey will organize and record a webinar to present the results to a nationwide audience. That webinar will be posted to Dr. Cassey's website above.

Possible Additional Information:

We intend to disseminate the information learned from this research as broadly as possible, and to continue to do so beyond the project end date.

8. Additional presentations at commodity association and transportation association meetings in as opportunity arises. We plan to submit the paper for inclusion in the annual Transportation Research Forum meetings, Toronto, May 1–3, 2016.
9. Additional academic seminars at universities or conferences as opportunity arises.

All materials for public dissemination will be made available in electronic format complying with Section 508 of the Rehabilitation Act as amended by the Workforce Investment Act of 1998.

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Assessing Post-Harvest Labor Shortages, Wages, and Welfare*

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Abstract

For horticultural commodities, labor is necessary for post-harvest activities such as management, marketing, packing, and distribution. We create a model with unskilled labor, skilled labor, and transportation to study the competitive equilibrium against a scenario where a fixed wage creates a labor shortage. Parameterized to data from the U.S. pome and prunus industries, we find prices are 11% higher in the fixed wage scenario, prunus does less well in adjusting, and producers benefit despite output reductions. When the impacts to the transportation network are considered, the negative effects are magnified and producers suffer sizable welfare losses as well.

JEL classification: J43, Q13

Keywords: post-harvest, skilled labor shortage, transportation, marketing, welfare

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1 Introduction

Labor is an important input into the production and distribution of horticultural commodities and products. In the literature, labor shortages are usually thought of as a pre-harvest problem, and the economic impacts are estimated from models related to harvesting and production, as in Richards and Patterson (1998) for example. Although labor is necessary for growing and harvesting horticultural commodities, it is also an important input into managing, marketing, processing, packing, transporting, and distributing of commodities to market post-harvest. Delays in the post-harvest delivery result in spoilage and quality loss. Thus the economic consequences of unskilled labor shortages on skilled labor and downstream commodity markets are unknown. This unknown is an important problem because post-harvest labor shortages undermine the best methods for managing, marketing, and delivering quality agricultural products and thus inefficiently distort the overall commodity markets. Agricultural labor shortages have become such a large problem that the awareness of them has spread from inside the industry to the general public. Examples in the media include Hecht (2013) and Wheat (2013). In 2011, Washington State made headlines by deploying inmates to help with the apple harvest (Hotakainen, 2011).

Post-harvest labor shortages can be seen as an agricultural marketing problem because of how it affects output delivered to market and final sales price. Wells (2012) reports anecdotal evidence suggesting labor shortages are affecting the competitiveness of the U.S. horticulture sector as agricultural consumption may shift to overseas products from Mexico or China for example. Kantor, Lipton, Manchester and Oliveira (1997) estimate that post-harvest losses in the United States can be as large as 23% for fruit (including consumer food losses). Despite advances in the environmental and biological control of post-harvest loss, socioeconomic constraints exist throughout the post-harvest supply chain (Kader, 2004). Appropriately skilled, located, and available labor is among the crucial inputs into the production, distribution, and marketing of agricultural commodities and products. As the perishability of the produce increases, so too does the necessity to appropriately synchronize labor activities as the produce is moved from the field to a centralized packing or processing facility, and then to the consumer market. Producers, regardless of size, may find the marketing, distribution, and delivery process cumbersome as they must acquire and coordinate their onsite labor, the transportation to get their product off the farm, a packing facility close enough to minimize transit time, delivery to the consumer, and the marketing of the product.

There has been work in the logistics field to estimate the costs of commodity loss along the transportation network. For example, Jessup and Herrington (2005) estimate the additional cost of shipping Washington produced apples to domestic and international markets due to shortages of truck drivers by estimating the cost of shipping to those destinations during the offseason and then applying those offseason rates to seasonal shipping volumes. They then compare the differences in predicted and actual prices yielding an estimate of a $12 million loss. Blackburn and Scudder (2009) create a model where they maximize the value of the product delivered to the customer. They find the critical period of product spoilage and devaluation is between harvest and cooling or freezing. The length of this time period is largely determined by the availability—or lack thereof—of truck drivers. Bogataj, Bogataj and Vodopivec (2005) show that any change in time-distance (or temperature) in the supply chain could greatly affect the net present value of the commodity and thus this is an important aspect to consider.

We define a labor shortage as the difference between the number of workers of a certain skill level willing and available to work and the number of workers desired by producers given the going market wage. We define skilled labor as the employment in occupations related to management, marketing, transportation, purchasing, accounting, and mechanics. Unskilled labor is the employment in occupations related to producing, harvesting, sorting, cleaning and packaging, data entry and payroll, ordering and retail, and maintenance. The degree of substitutability of labor types is relatively low. Post-harvest is the time when the bulk of the crop is separated from its parent plant to purchase by a consumer. It is the stage of the process covering the cooling, cleaning, sorting, packing, and transporting of products to consumers and we explicitly consider the impact to output from spoilage along the transportation network if there is a labor shortage.

Building from the foundation set by Muth (1964) and the two stage estimation strategy in Gunter, Jarrett and Duffield (1992), we develop an equilibrium displacement model of the U.S. pome (apple) and prunus (peach) commodity output market, their shared skilled labor market, and their shared unskilled labor market. In addition, our model explicitly accounts for the post-harvest distribution and transportation delivery network by including a commodity specific decay or spoilage parameter realized as a change in productivity. Transportation is an important part of the production and delivery process and also very important for the marketability of U.S. fruit so that fresh and unblemished produce arrives in stores. However this is an aspect missing from most studies on the effect of pre-harvest labor shortages.

We shock the model with an increase in commodity demand from population growth and also a decrease in unskilled labor supply based on the prediction in Gallardo, Brady, Jiang, Juraqulova and Mendoza (2014). First, we estimate the change in price, output, employment, and wages in order for the pome, prunus, skilled labor, and unskilled labor markets to achieve a new competitive equilibrium. Next we repeat the shock when we fix the wage for unskilled and skilled workers at the pre-shock level. We calculate the change in the equilibrium and welfare with these fixed wages as well as the size of the labor shortages and the associated deadweight loss. We compare the results from the model with fixed wages to those in the flexible-wage competitive equilibrium to understand how a shortage in unskilled labor affects post-harvest activities such as marketing and distribution. We then repeat the exercise with a spoilage rate parameter in order to assess the importance of the transportation and delivery chain in a labor shortage.

The model is parameterized using data from the U.S. pome and prunus industries because of their large total value of production—almost $3 billion in 2010—and their geographic spread across the contiguous states—29 for pome and 23 for prunus (USDA-NASS various years). Therefore, our findings will apply to multiple states as well as being illustrative of the problem to the greater agricultural sector.

Our modeling focus is designed to estimate how the downward shift of unskilled labor supply affects producers' demand for skilled post-harvest labor such as those in the managing, marketing and distribution occupations. We explicitly consider and model the spoilage rate along the transportation network in order to get a better estimate for the deadweight loss associated with a labor shortage that may differ among commodities that spoil at different rates. We estimate that given the plausible shocks of a 5.4% increase in final demand and a 7% decrease in unskilled labor supply, wages of skilled and unskilled labor would need to increase by 2.8% and 6.4% for the markets to clear. When we fix wages at the pre-shock level, prices increase by slightly more than 11% for both pome and prunus compared to the post-shock competitive equilibrium and output decreases by 5.6% for pome and 13.1% for prunus. We find that the deadweight loss associated with the estimated labor shortages in unskilled and skilled labor are \$15.5 million for the pome and prunus output markets combined and \$43.4 million for the labor markets combined, measured in 1982–1984 dollars.

Yet despite the inefficiency in the economy from the labor shortage, producers' welfare increases relative to the competitive outcome because the labor-shortage-induced decrease in output is more than made up for by the increased prices obtained by sellers as well as the surplus obtained from paying a lower than competitive wage in both labor markets. The gain to pome firms is \$350.5 million, and the gain to prunus firms is \$41.8 million, again measured in 1982–1984 dollars.

When we include commodity-specific spoilage rates to explicitly consider the impact of a labor shortage on the transportation network, we find the prunus industry, which has the faster spoilage rate, is severely impacted whereas the losses in the pome market are tempered. Prunus output decreases by 44.9% and prices increase by 37.6% compared to the post-shock competitive equilibrium whereas pome output decreases by only 1.7% with prices increasing 10.4%. Thus a labor shortage in the transportation sector harms some industries more than others. However, inclusion of the transportation network yields results showing that producers for both the pome and prunus industries are harmed by the labor shortage instead of gaining as in the case without the transportation network. The pome industry suffers an economics surplus loss of \$179.0 million or 8.4% of the pre-shock revenue. The prunus industry suffers an economic surplus loss of \$160.8 million or 32.4% of the pre-shock revenue. This shows the importance of modeling the transportation sector as well as understanding how important labor shortage mitigation is to producers.

2 A Two Good Equilibrium Displacement Model with Labor

We use an equilibrium displacement model to quantify the impact of a positive output demand shock coupled with a negative unskilled labor supply shock on the quantity and price of the two final goods and the equilibrium wages and employment in the unskilled and skilled labor markets. We are particularly interested in how these shocks work through the skilled labor market, which represents post-harvest occupations such as managing, marketing, and transporting and delivering the produce. Our model is constructed using Muth (1964) as a foundation. The Muth model is a system of reduced-form equations of the competitive equilibrium of a single-good competitive industry and its associated competitive input markets. Nonprice shocks are applied to the model, which yields new competitive wages, employment, output quantity, and prices. The magnitude of the changes in prices and quantity depends on the nonprice elasticity of the input market demand and supply curves and the price elasticity of the demand and supply curves in the output commodity market.

We expand the single good modeled in the Muth (1964) paper to consider two goods in perfectly competitive markets: pome and prunus. These output markets are related to each other through nonsymmetric cross price elasticities of demand. Also, our version of the Muth model is constructed by having two labor inputs: unskilled labor and skilled labor. As in Gunter, Jarrett and Duffield (1992), the two commodity industries demand unskilled and skilled labor from the same pool of available workers in the unskilled and skilled labor input markets. These input markets are competitive and partially related in the sense that unskilled labor cannot easily transfer to the skilled labor market to seek higher wages. Because the focus is on labor markets, we do not explicitly model other inputs to production such as land, capital, or materials. The competitive equilibrium in the model occurs when output quantity and price for each commodity, skilled labor wage and employment, and unskilled labor wage and employment are such that the four markets clear. The parameters of the model:

1. the price elasticity of demand facing each industry (η_i),
2. the cross price elasticity of demand facing each industry (κ_{ij}),
3. the price elasticity of supply for each skilled labor type (e_ℓ), and
4. the elasticity of substitution between skilled and unskilled labor in production (σ)

where $i, j \in \{pome,\ prunus\}$ and $\ell \in \{skilled,\ unskilled\}$. There are also the shock parameters:

5. the nonprice shift in demand for output of each industry (γ_i),
6. the nonwage shift in labor supply of each skill type (α_ℓ), and

7. the commodity specific factor-neutral productivity shock from spoilage along the transportation network (Γ_i).

The details of the model may be found in appendix A. Worthy of comment, though, is the elasticity of substitution between skilled and unskilled labor, σ, is symmetric but does not apply to different tasks or occupations within skill level. That is, there is perfect mobility of skilled labor between the skilled tasks such as marketing, transportation, and distribution of the commodity and there is perfect mobility of unskilled labor between the unskilled tasks such as sorting, packing, and processing.

Also worthy of comment is the commodity-specific factor-neutral productivity shock, Γ_i. We model the time when the commodity is traveling along the transportation network as a technology in the production *and delivery* of the output to consumers at market. The spoilage rate of produce becomes part of the productivity parameter in the technology function as it takes more labor to deliver the same amount of quality produce than if there is no spoilage rate. What we are suggesting is that due to driver shortages (or other laborers en route) the necessary transit time from harvest to market increases, thus output loss from spoilage also increases. This results in less product on the market per unit of labor. If the spoilage rate is different across products, then Γ_i is different across products. A lower value of Γ indicates lower productivity: fewer output is delivered to market with the same amount of workers than a with higher value of Γ. This allows for greater precision in calculating the commodity-specific welfare estimates.

Following Gunter et al. (1992), we implement our version of Muth's model in two stages. In the first stage, we calculate wage and employment changes in the unskilled and skilled labor markets due to the two shocks. There is feedback from wage changes in the skilled market to the unskilled market (and vice versa) via the symmetric elasticity of substitution σ. In the second stage, the wages and employment from the skilled and unskilled labor markets calculated in the first stage are entered into the producer's problem for the individual pome and prunus industries. This results in a calculation of the changes in output and price in the pome and prunus commodity markets. There is feedback from the price change in one output market on the other output market via the nonsymmetric cross price elasticity of demand κ. That κ is not symmetric means that the sensitivity of demand of pome to price changes in the prunus market is not the same as the sensitivity of demand of prunus to price changes in the pome market.

By using the two stage approach of Gunter et al., we are assuming that the pome and prunus industries are drawing skilled and unskilled labor from the same aggregate labor input markets. This is done because the labor markets facing each industry are quite similar in the sense that though there is not perfect substitutability between skilled and unskilled labor within a market, there is essentially perfect substitutability of labor within skill-types between the pome and prunus industries. For example, a truck driver can deliver either apples or peaches from the orchard to the packer but a picker cannot easily get a license to be a commercial truck driver. This approach also allows us to model the output and price changes in pome and prunus markets simultaneously and in relation to each other. By giving the model values for the parameters, the equilibrium may be solved for uniquely. The result should be considered a national model of the pome and prunus industries as we do not separately parameterize regions within the United States.

3 Parameterization and Shocks

3.1 From the Literature

The model is parameterized using estimates from the literature. Table 1 shows the values used and the sources are discussed below.

Maintaining consistency with U.S. Department of Agriculture benchmarks, we use the values in Henneberry et al. (1999) for the price elasticity of demand for the pome and prunus industries. One difference between these industries is that consumer demand for pome is price inelastic but slightly price elastic for prunus. The price elasticity of demand for pome is -0.59 whereas it is -1.11 for prunus. Unlike Liu, Chouinard, Marsh and LaFrance (2014) and other recent papers that use only a single year of data to estimate the price elasticity, Henneberry et al. use data covering more than 20 years for their estimates. Furthermore, Henneberry et al. provide Marshallian elasticities, which is more appropriate to use in surplus calculations than the Hicksian elasticities in Liu et al.

We take the cross price elasticities of demand from Henneberry et al. (1999) as well. The cross price elasticity for pome to changes in the price of prunus is 0.12 whereas it is 0.02 for prunus to changes in the price of pome. Though both are (weak) substitutes for each other, that these are

Table 1. Parameters and Shocks

Parameter	Description	Value
η_{pome}	Price elasticity of the industry demand for pome	−0.59[a]
η_{prunus}	Price elasticity of the industry demand for prunus	−1.11[a]
$\kappa_{pome,prunus}$	Cross price elasticity of the industry demand for pome to prunus	0.12[a]
$\kappa_{prunus,pome}$	Cross price elasticity of the industry demand for prunus to pome	0.02[a]
$e_{skilled}$	Supply elasticity for skilled labor input	0.73[b]
$e_{unskilled}$	Supply elasticity for unskilled labor input	3.37[c]
σ	Elasticity of substitution between skilled labor input and unskilled labor input	1.10[d]
γ	Nonprice shift in demand for pome and prunus (demand shock)	5.4%[e]
$\alpha_{unskilled}$	Nonwage shift in supply for unskilled labor (labor shock)	−7.0%[e]
Γ_{pome}	Transportation & spoilage productivity shock for pome	1.10[f]
Γ_{prunus}	Transportation & spoilage productivity shock for runus	0.71[f]

Sources: [a]Henneberry, Piewthongngam and Qiang (1999), [b]Duffield (1990), [c]Perloff (1991), [d]Card and Lemieux (2001), [e]Gallardo et al. (2014), and [f]authors' calculations.

asymmetric is another example of how the pome and prunus industries differ. Demand for pome is relatively more sensitive to price changes of prunus than prunus is for pome.

There does not seem to be a consensus estimate of the price (wage) elasticity of supply for skilled agricultural labor, especially for post-harvest occupations. This is perhaps not surprising as our research is among the first to consider post-harvest labor issues. Thus a consensus estimate for this parameter is not available from the literature. Instead we use the value from Duffield (1990). Using forty years of data, he estimates the supply elasticity for hired farm labor to be 0.73. In checks in appendix table B.3, we vary this parameter to determine how sensitive our results are to changes in the parameter value and find our results are qualitatively robust and quantitatively similar.

From Perloff (1991) we obtain the price elasticity of supply for unskilled labor. Perloff discusses the impact of wage differentials in choosing agricultural work. Based on a model of industry choice and wage determination, he estimates the quantity response of average agricultural unskilled labor to a 1.00 percent increase in the relative wage is 3.37 percent. Perloff also estimates the likelihood of nonagricultural workers joining the agricultural work force in response to an increase in the agricultural wage. In appendix table B.4 we test the sensitivity of our results to this parameter. Again we find slight, but economically sensible, quantitative changes but qualitative robustness of our results.

Likewise, there are no estimates in the literature of the elasticity of substitution between skilled and unskilled agricultural labor. The closest study is Card and Lemieux (2001) who find an elasticity of 2 between college educated and high school educated males. The elasticity needed for our model is likely to be lower than that as not only are the skill types different, the tasks each skill group performs are different. For example, it would be difficult for an unskilled picker to learn and get licensed to drive a large commercial truck hauling fresh fruit just as it would be difficult for an accountant to be a part of the processing line. An elasticity of substitution of 1.1 was chosen as it is the lowest of the several estimates Card and Lemieux (2001) report, and this value is symmetric. We report results using values of 0.7 and 1.5 as well.

The two remaining parameters from the literature are for the shocks to the economy. We set a 5.4% outward shift of the demand curve for fresh produce. This value is from Gallardo et al. (2014), who estimated it by using an annual population growth rate of 0.009% with estimated per capita availability of total fruit and vegetable growth rate of 0.0018%. The prediction from Gallardo et al. of a 7% inward shift of the unskilled labor supply curve is also used, which represents the decrease in the number of migrant workers in five years. We also shock the model by 2%, 5%, and 11% for robustness. Those results may be found in appendix table B.4. We shock the model simultaneously as Gallardo et al. predict each of these events will happen in the next five years.

3.2 From the Data

We use data on output prices and quantities as well as labor inputs and wages to calculate the benchmark economy. We use panel data on occupational wages and employment from the Occupational Employment Statistics Survey (OES) of the U.S. Department of Labor.[1] We use data from 2002 through 2010. Employees in the data set are all part-time and full-time workers who are paid a wage or salary. The survey does not cover the self-employed, owners and partners in unincorporated firms, household workers, or unpaid family workers. From that database, we select the information in "Support Activities for Crop Production" (NAICS 115100). This is the industrial subsector most closely aligned with post-harvest labor including marketing and distributing commodities. The OES does not further break down employment and wage data into specific commodities such as pome or prunus. Guided by economic theory about no arbitrage in competitive

[1] http://www.bls.gov/oes/tables.htm.

equilibrium, we assume that the wages for the same skill-level are equal for the pome and prunus industries. Otherwise the agricultural labor market would not clear. This assumption is the essence of the two-stage procedure to calculate changes to the equilibrium from the two shocks applied to the model.

We further refine the employment and wage data by partitioning the data into occupations requiring skilled labor and occupations that may use unskilled labor. This partition is done by using Standard Occupational Codes provided by the U.S. Department of Labor's O*net Online.[2] All standard occupational codes are divided into five categories based on the skill needed to perform the task. Those occupations that have a 1 or 2 code are classified as being able to use unskilled labor whereas skilled labor is required for occupations coded 3 to 5. We did, however, classify occupations related to transportation and truck driving as skilled though the Standard Occupational Codes for that activity is coded as a 2. Next, we kept only those occupations that are related to post-harvest labor. For example, we eliminated occupations such as tree trimmers and pruners, cutters, and horticultural and soil scientists since these occupations are more related to pre-harvest labor, as well as agricultural inspectors.

The OES does not provide data for all occupations for all years. We build a useable panel by first selecting only those occupations that contain data in more than 4 years out of the total 9 years of the sample. We estimate the missing data by averaging the two years around it. If there is more than one year of missing data consecutively, we average the three years before or after the missing years. This procedure allows us to classify and use data on 30 skilled occupations and 51 unskilled occupations. We then calculate the average real wage over the years, using 1982–1984 as the base year, by occupation and use an employment-weighted average to calculate wages in the aggregate skilled and unskilled labor markets.

Price and output data for apples and peaches are available from the USDA-ERS (various years).[3] We use the data for total fresh fruit production delivered to consumers rather than harvest quantity as we are interested in the importance of timely post-harvest distribution. Furthermore, we do not use data on production of canned or processed fruit products. We convert the nominal price data

[2]http://www.onetonline.org/.

[3]http://www.ers.usda.gov/data-products/fruit-and-tree-nut-data/yearbook-tables.aspx#40907.

Table 2. Summary Statistics

Variable	Mean	Std. Dev.	Min.	Max.
Skilled Employment (thousand)	27.18	0.80	25.82	28.22
Unskilled Employment (thousand)	257.92	9.70	245.56	271.05
Skilled Weighted Real Wage ($/hour)	9.49	0.34	9.04	9.97
Unskilled Weighted Real Wage ($/hour)	4.53	0.10	4.41	4.68
Pome Production (mil.lb)	6085.07	413.66	5366.00	6619.00
Prunus Production (mil.lb)	1031.23	75.89	882.40	1134.40
Pome Real Retail Price ($/lb)	0.35	0.03	0.31	0.41
Prunus Real Retail Price ($/lb)	0.48	0.03	0.45	0.53

Notes: Data are stats for the yearly averages from 2002–2010.
Source: U.S. Dept. of Labor OES and U.S. Dept. of Agriculture ERS Fruit and tree nut year book (2014). Real values are calculated using 1982–1984 as base year.

to real values using 1982–1984 as the base year. As with the labor markets, we average the real prices and quantities to produce aggregate values.

Table 2 shows the summary statistics for employment, wages, production, and prices by commodity. One key point to notice in table 2 is that the size of the unskilled labor force is about an order of magnitude larger than the skilled labor force and wages for skilled workers are more than twice that of the unskilled. Another key point is that pome market is about six times larger than prunus. However, the prunus price exceeds the pome price by almost fifty percent.

To calculate the differences in the pre- and post-shock equilibria, we need the slope of the skilled labor supply curve and the skilled labor demand curve. We calculate the slope of the skilled labor supply curve directly from the model. However, the slope of the skilled labor demand curve cannot be calculated from the model. Instead, we estimate the slope from data. We average the data on real wage and employment from skilled occupations in 2006 and 2010. The change in real wage over the change in employment is calculated by assuming the variation in the data was caused by shifts in the supply of the labor curve. The calculated slope of skilled labor demand curve is -0.14, which is used to calculate post-shock equilibria.

We model the transportation network by altering labor productivity from the default level of one. As detailed in appendix A, we estimate that $\Gamma_{pome} = 1.01$ and $\Gamma_{prunus} = 0.72$, confirming with our data and our model the fact that prunus spoils more quickly than pome (Becker and

Fricke, 1996). We arrived at this by first setting one as a standard value of Γ, which does not change a worker's productivity. Second, we calculate the value of the factor-neutral productivity shift for pome and prunus by using the estimated Γs. We increase the factor-neutral productivity shift parameter by 1% for pome because $\Gamma_{pome} = 1.01$ and decrease it for prunus by 28% because $\Gamma_{prunus} = 0.72$. Finally, we apply these parameters into the model and repeat the post-shock calculations.

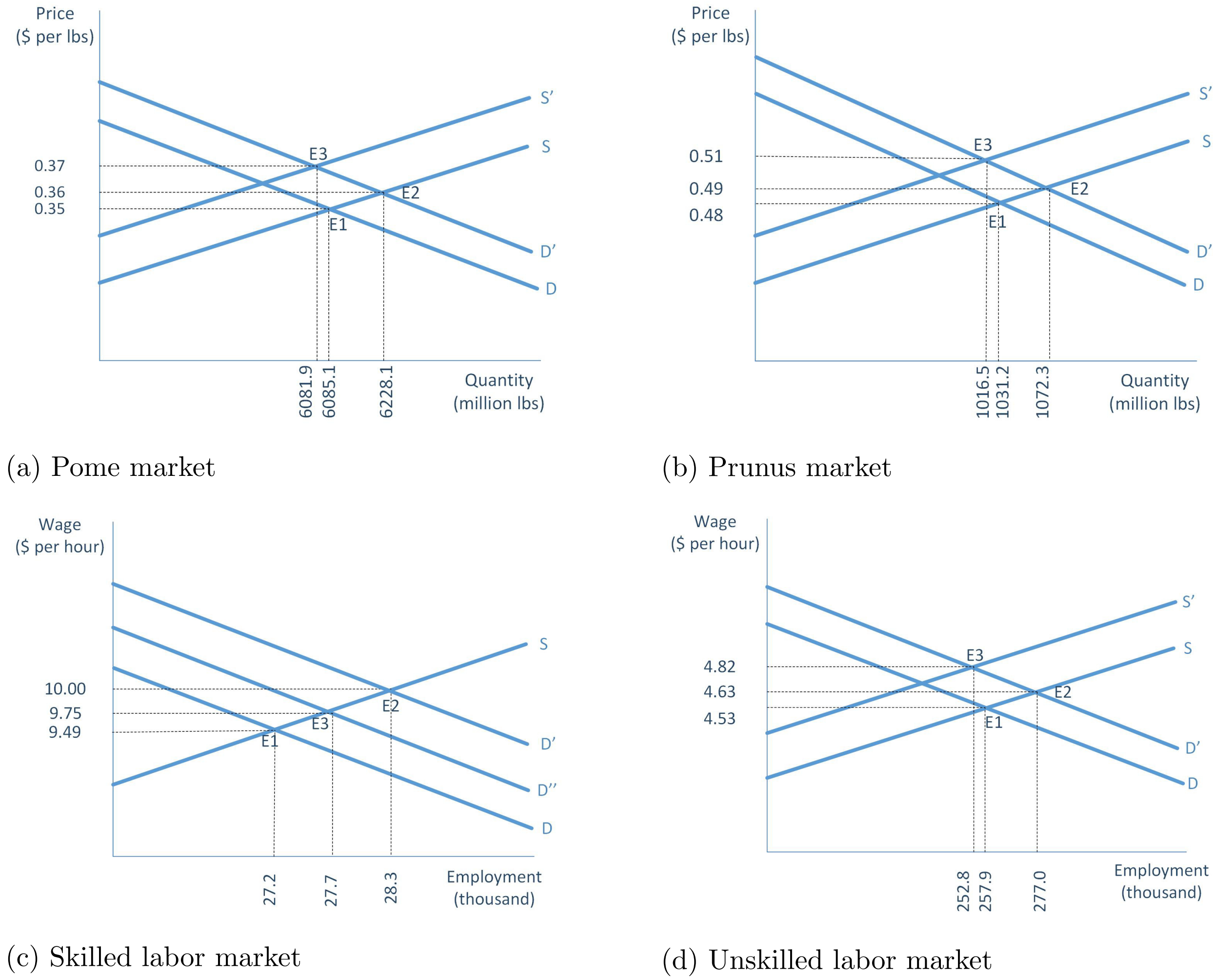
4 Results

4.1 Competitive Equilibrium Pre- and Post-Shock

We first have the model calculate the pre-shock competitive equilibrium to match the data from table 2. That is seen in figure 1, which displays the pome and prunus output markets as well as the skilled and unskilled labor markets. The pre-shock competitive equilibrium is designated E1. Note the demand curve in the pome market is more price inelastic at -0.59 then the prunus market at -1.11. There is not a labor shortage in either the unskilled or skilled labor markets. The competitive wage is \$9.49 for skilled labor and \$4.53 for unskilled labor in 1982–1984 dollars. Total employment is 27,180 for skilled labor and 257,900 for unskilled labor. The price of pome is \$0.35 and quantity sold is 6.085 billions pounds whereas price is \$0.48 for prunus and 1.031 billion pounds are sold.

Next, we shock the model with a 5.4% increase in output demand for both pome and prunus from population growth. This is seen in figure 1 with D' and the new equilibrium is designated by E2. Note that the shifting out of the demand curve is direct for the pome (a) and prunus (b) output markets, but it is indirect in the skilled (c) and unskilled (d) labor input markets. That is, because of the increase in demand for output, producers demand more labor for each wage rate, and thus D' shifts out compared to D in the input markets.

At the same time we shock the model with a 7% decrease in the supply of unskilled labor. This is seen in figure 1 as S' to the left of S in panel (d) and the new equilibrium is designated E3. The resulting post-shock competitive equilibrium has a higher wage for unskilled labor. That means the costs of production of pome and prunus increases and thus S' shifts to the left and is higher than



(a) Pome market

(b) Prunus market

(c) Skilled labor market

(d) Unskilled labor market

Figure 1. Pre-shock and post-shock competitive equilibrium for the fresh pome, prunus, skilled labor, and unskilled labor markets.

S in panels (a) and (b). Producers respond to the increase in unskilled wage by reducing unskilled labor employment from 257,900 to 252,800 in the post-shock competitive equilibrium.

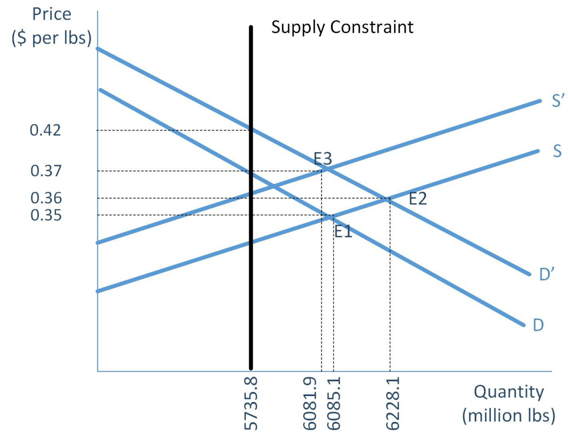
Because there is a decrease in unskilled employment, there is also a decrease in output for both the pome and prunus industries at the E3 competitive equilibrium compared to E1. Since there is less output, producers hire fewer skilled workers compared to E2 in panel (c), which is seen by D'' being to the left of D'. The amount of skilled employment increases in E3 compared to E1 because though output is decreasing, producers are trying to make up for the loss of unskilled labor by substituting with skilled labor. However, with $\sigma = 1.1$ firms cannot readily replace unskilled workers with skilled workers. The end result is that unskilled wages increase 6.41% or \$0.29 per hour and unskilled employment falls 0.55% and 1.87% for the pome and prunus industries, respectively. Skilled wages increase 2.77% or $0.26 per hour and employment increases slightly. Neither the skilled nor unskilled labor markets experience a labor shortage as the wage adjusts to prevent this. Since our main results compare the post-shock competitive equilibrium to the post-shock fixed wage scenario, we relegate the detailed results comparing the pre-shock competitive equilibrium to the post-shock competitive equilibrium to appendix table B.1 for percent change and table B.2 for level change.

4.2 Post-Shock Equilibrium and Fixed Wage Labor Shortage Outcome

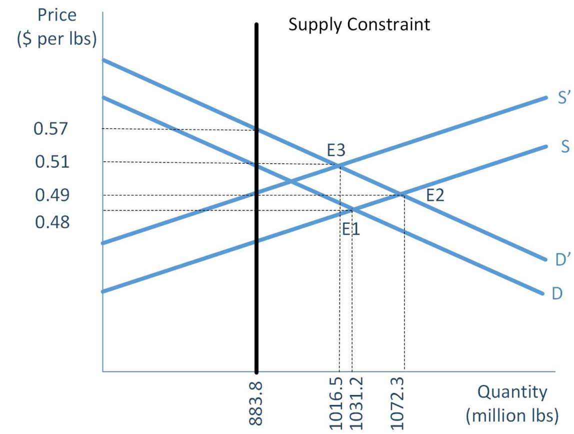
We fix the wage for unskilled and skilled labor at the benchmark level of the pre-shock equilibrium E1. Shocking the model with an unskilled labor supply decrease when there is a fixed wage creates a labor shortage rather than a higher wage. These shortages are realized as a supply constraint in the output market. Because competitive equilibrium is neither obtained in the output, skilled labor, nor unskilled labor markets, inefficiency and deadweight loss is present in all four markets.

Figure 2 shows the pome and prunus output markets and the skilled and unskilled labor input markets when the wages of labor has been fixed at its pre-shock levels and $\sigma = 1.1$. In panel (d), the number of employed unskilled workers decreases *more* than the decrease in the competitive equilibrium scenario because there is no increase in wage to induce additional unskilled workers to enter the market. We estimate the amount of unskilled labor employed in the pome and prunus industry decreases from 257,900 to 198,900 if the wage remains at the initial level of $4.53 whereas employment would only fall to 252,800 if the competitive wage were offered at $4.82 in 1982–1984 dollars. Because of the increase in final demand, however, the derived demand for unskilled labor shifts out to D' from D in panel (d). This means that though employment has dropped from 257,900 to 198,900, the industry wishes to employ 289,200 workers at a wage of $4.53. Thus, the predicted unskilled labor shortage in the pome and prunus market is 90,300 or about 35% of the pre-shock level of employment.

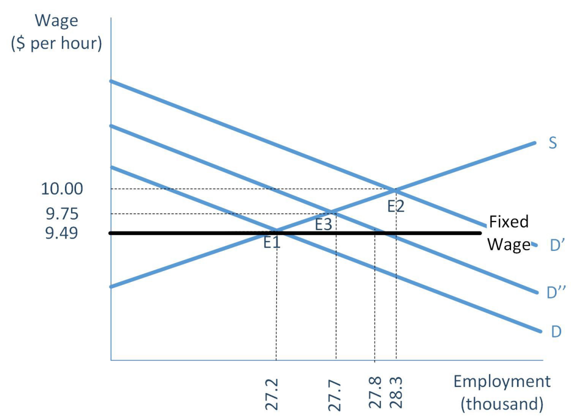
The pome and prunus industries would like to use more skilled labor to at least partially offset the reduction in unskilled labor. However with the wage for skilled labor fixed at $9.49, no additional skilled workers agree to work as seen in panel (c). Firms wish to increase skilled labor



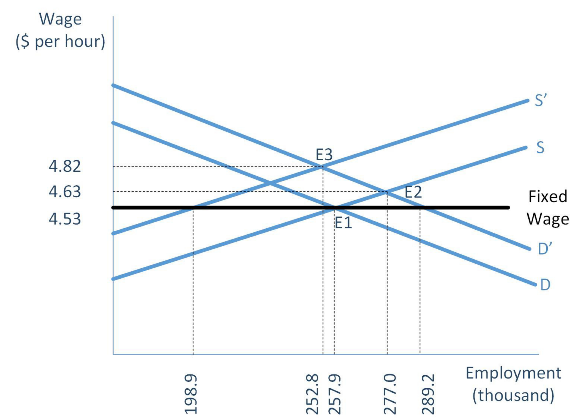
(a) Pome market



(b) Prunus market



(c) Skilled labor market



(d) Unskilled labor market

Figure 2. Post-shock fixed wage scenario for the fresh pome, prunus, skilled labor, and unskilled labor markets.

employment from 27,200 to 27,800, thus creating a skilled labor shortage of 600 workers or 2.2% of the pre-shock level of employment.

Since firms cannot hire additional skilled labor, the full brunt of the shocks are passed through onto production and are realized as a supply constraint in the output market. That can be seen in panel (a) and (b) as the supply constraint created by the shortage of both unskilled and skilled labor is well below the competitive equilibrium amount of output. For the pome industry, the shortfall is 346.1 millions lbs from the post-shock competitive level. The sales price increases to

Table 3. Post-Shock Equilibrium and Fixed Wage Outcome Percent Change

σ	Output	Output price	Skilled emp.	Skilled wage	Unskilled emp.	Unskilled wage
			(percent change)			
			Pome			
0.7	-6.03	11.85	-3.46	-1.90	-8.12	-6.46
1.1	-5.69	11.27	-4.46	-2.77	-8.11	-6.41
1.5	-5.40	10.69	-5.12	-3.35	-8.43	-6.38
			Prunus			
0.7	-13.76	11.64	-1.95	-1.90	-13.57	-6.46
1.1	-13.05	11.44	-3.02	-2.77	-13.06	-6.41
1.5	-12.41	10.53	-3.72	-3.35	-13.19	-6.38

Notes: $e_s = 0.73$, $e_u = 3.37$, 5.4% final demand shock, and -7% unskilled labor supply shock.

Table 4. Post-Shock Equilibrium and Fixed Wage Outcome Level Change

σ	Output (mil. lbs)	Output price ($ / lbs)	Skilled emp. (ones)	Skilled wage ($ / hr)	Unskilled emp. (ones)	Unskilled wage ($ / hr)
			Pome			
0.7	-366.3	.05	-781.9	-.18	-16777.8	-.29
1.1	-346.2	.05	-1007.8	-.26	-16902.7	-.29
1.5	-328.6	.04	-1156.0	-.31	-17413.7	-.29
			Prunus			
0.7	-139.6	.06	-88.2	-.18	-5536.7	-.29
1.1	-132.6	.06	-136.7	-.26	-5329.6	-.29
1.5	-126.3	.05	-168.3	-.31	-5386.7	-.29

Notes: $e_s = 0.73$, $e_u = 3.37$, 5.4% final demand shock, and -7% unskilled labor supply shock.

$0.42 per pound from the $0.37 per pound post-shock competitive price.[4] Thus the labor shortages are causing the additional cost to the consumer of $0.05 per pound. For the prunus industry, the shortfall is 132.7 million lbs and an increase in price to $0.57 per pound from $0.51 per pound post-shock.

Table 3 shows the percent changes and table 4 shows the level changes from the post-shock competitive equilibrium to the post-shock scenario with fixed wages. We report the results for our preferred benchmark with $\sigma = 1.1$ as well as a robustness check when we vary σ. Because σ is the symmetric elasticity of substation between skilled and unskilled labor, it becomes increasingly difficult to substitute labor across skill-types from σ of 1.5 to 0.7. Thus the impact of the fixed wage

[4]These values are rounded for convenience in exposition.

becomes larger as σ decreases because the industries cannot adjust by changing the employment composition as easily. As can be seen, the fixed wage scenario and labor shortages leads to an outcome with substantially less output, higher prices, and lower employment than the post-shock competitive equilibrium outcome regardless of the value of σ.

4.3 Post-Shock Fixed Wage Transportation, Spoilage and Productivity

Timely delivery of produce to market is a key aspect for the marketability of U.S. produce and thus the transportation network should be considered. Yet transportation is often disregarded in production models. Our results above show there will be a shortage of skilled labor such as truck drivers during the important post-harvest time. Thus we account for these impacts by explicitly accounting for spoilage along the transportation network.

We estimate the productivity adjustment representing spoilage along the transportation network for pome and prunus. We then modify the model by adjusting the commodity-specific factor-neutral productivity parameter based on those estimates. The estimates reflect relative differences in spoilage rates between the two commodities and are not relevant or comparable to data outside the model. Compared to the benchmark of one used above, we boost the productivity of pome production and delivery by 1% relative to the benchmark of one. We also decrease the productivity of prunus 28% relative to the benchmark of one. These adjustments reflect the well-known fact that prunus spoil much more quickly than pome as well as the fact that pome can be stored whereas prunus cannot. See appendix A for details.

The results, available in table 5 as percent changes and table 6 as level changes, compare the post-shock competitive equilibrium to the post-shock outcome with fixed wages and the effects of the transportation network. Thus the results are directly comparable to table 3 and table 4. The asymmetric effect of the spoilage rate creates a lopsided outcome that greatly favors the pome industry over the prunus industry. The pome industry experiences slightly lower prices than with fixed wages only, dropping from 11.27% above the competitive price to 10.39% above the competitive price. Output increases from 5.69% below the competitive output to 1.71% below the competitive output. However, the prunus industry is greatly affected by the slowdown in transportation. The price of prunus increases dramatically as well as a large reduction in output. Skilled employment

Table 5. Post-Shock and Post-Shock with Fixed Wage and Transportation Effect Percent Change

σ	Output	Output price	Skilled emp.	Skilled wage	Unskilled emp.	Unskilled wage
			(percent change)			
			Pome			
0.7	-2.02	10.90	-3.46	-1.90	-14.27	-6.46
1.1	-1.71	10.39	-4.46	-2.77	-13.89	-6.41
1.5	-1.42	9.81	-5.12	-3.35	-13.55	-6.38
			Prunus			
0.7	-45.79	38.16	-1.95	-1.90	-7.71	-6.46
1.1	-44.94	37.57	-3.02	-2.77	-7.37	-6.41
1.5	-44.21	37.03	-3.72	-3.35	-7.10	-6.38

Table 6. Post-Shock and Post-Shock with Fixed Wage and Transportation Effect Level Change

σ	Output (mil. lbs)	Output price ($ / lbs)	Skilled emp. (one)	Skilled wage ($ / hr)	Unskilled emp. (one)	Unskilled wage ($ / hr)
			Pome			
0.7	-122.92	0.04	-781.9	-.18	-29490.34	-0.29
1.1	-104.16	0.04	-1007.8	-.26	-28690.17	-0.29
1.5	-86.41	0.04	-1156.0	-.31	-27985.33	-0.29
			Prunus			
0.7	-464.66	0.20	-88.24	-.18	-3143.30	-0.29
1.1	-456.82	0.19	-136.7	-.26	-3010.23	-0.29
1.5	-449.91	0.19	-168.3	-.31	-2898.37	-0.29

Notes: $e_s = 0.73$, $e_u = 3.37$, 5.4% final demand shock, and -7% unskilled labor supply shock.

remains the same as in the fixed wage scenario but unskilled labor is shifted from the pome industry to the prunus industry compared to the fixed wage only scenario. The reason for this is that much of the unskilled labor that used to be going for production is now compensating for the decrease in productivity in the prunus industry.

The aggregate labor markets are unaffected when transportation is considered. That is because despite the change to productivity, wages cannot adjust due to the fixed wage. Furthermore, despite the labor shortage, there is the same level of employment in the fixed wage scenario with the transportation network as without. That same employment, however, yields a change in output overall because of the productivity adjustment to represent spoilage along the transportation network.

The effect of the transportation network is felt in the output markets through the price and output. The high spoilage rate of prunus means the price of prunus increases further compared to the fixed price case. This effect is exacerbated because the relative price elasticity of demand for prunus means consumers are sensitive to the change in price of prunus. Consumers switch to increased demand for pome, which is why the output of pome increases by 242 million lbs compared to the fixed-wage only scenario. The low spoilage rate of pome means that transportation slowdowns are not as important as for prunus. Comparing these results with the results from without the transportation network reveals just how important accounting for transportation is.

4.4 Welfare Comparisons

We are interested in how the skilled and unskilled labor shortages affect the welfare of the economy. Because wages are flexible in the post-shock competitive equilibrium, the labor markets clear and there are no labor shortages. When the wage is fixed, however, the labor markets do not clear. Thus there are labor shortages, deadweight loss and economic inefficiency. Furthermore, the labor shortages create a supply constraint in the output markets and prevents those markets from clearing. Thus there is deadweight loss in those markets as well.

Table 7 shows the surplus changes associated with the labor shortages, comparing the post-shock competitive equilibrium to the post-shock fixed wage outcome. As can be seen, consumers are harmed in terms of lost economic welfare. Consumers lose $249.1 million in the pome market and an additional $57.7 million in prunus from the combination of the increase in output price and decrease in output available for consumption. Skilled and unskilled labor experience decreases in welfare as well, as the wage is lower than in competitive equilibrium and employment is less. Skilled labor experiences a welfare loss of $13.6 million and unskilled labor experiences a welfare loss of $130.8 million as measured in 1982–1984 dollars.

On the other hand, there are large gains to producers' welfare with the wage fixed at the pre-shock level. Though there is a labor shortage, the benefit to firms from paying a lower wage is greater than the cost of not producing and selling as much output. But there is an additional benefit to firms from the output market. That output is reduced allows producers to receive a higher price. Firms benefit in both the pome and prunus markets because they are able to capture much of the lost consumer welfare from the competitive outcome. The gain to pome firms is $239.2

Table 7. Economic Surplus

	Post-shock competitive equilibrium	Post-shock fixed wage	Welfare loss	Post-shock fixed wage transport	Welfare loss transport
Pome Commodity Market (million $)					
Consumers	2251.8	2002.7	249.1	2193.7	58.1
Firms	810.3	1049.5	-239.2	397.2	413.1
Total	3062.1	3052.2	9.9	2590.9	471.2
Prunus Commodity Market (million $)					
Consumers	236.5	178.8	57.7	67.0	169.5
Firms	89.2	141.3	-52.1	61.5	27.7
Total	325.7	320.1	5.6	128.5	197.2
Skilled Labor Market (million $)					
Skilled labor	333.8	320.2	13.6	320.2	13.6
Firms	1956.6	1969.4	-12.8	1969.4	-12.8
Total	2290.4	2289.6	0.8	2289.6	0.8
Unskilled Labor Market (million $)					
Unskilled labor	333.6	202.8	130.8	202.8	130.8
Firms	500.6	588.8	-88.2	588.8	-88.2
Total	834.2	791.6	42.6	791.6	42.6
Total Firms (million $)					
Total Pome Firms	2915.6	3266.1	-350.5	2736.6	179.0
Total Prunus Firms	441.1	482.9	-41.8	280.3	160.8

Notes: Surplus in labor markets is calculated by multiplying the estimated equilibrium wage times the average number of workers in each occupation that each industry uses and then adjusting for 40 hours per week for 50 weeks per year. Total Firm surplus is the sum of surplus from the specific commodity market plus the welfare from the skilled and unskilled labor markets determined by the ratio of industry employment to total employment for each skill type. Values reflect the 1982–84 base year.

million in just the output market and the gain to prunus firms is $52.1 million for just the output market. When the gains to producers from the labor markets are included, the pome and prunus producers increase welfare by $350.5 million and $41.8 million respectively.

Despite the gain to producers, though, the fixed wage outcome is economically inefficient. Deadweight loss is $9.9 million in the pome market, $5.6 million in the prunus market, $0.8 million in the skilled labor market, and $42.6 million in the unskilled labor market as measured in 1982–1984 dollars. Thus there are significant costs to the economy from the labor shortages.

The welfare implications of spoilage along the transportation network may be found in the right most two columns of table 7. The right most column is the comparison in welfare from the post-shock competitive equilibrium to the post-shock fixed wage with transportation network outcome and is thus comparable to the left welfare loss column. Across the economy, welfare is down compared to the post-shock competitive equilibrium.

In the pome market, even though consumer welfare decreases in the scenario with transportation compared to the competitive outcome, the welfare loss is much less than in the fixed-wage only scenario. That is because, benefitting consumers, the output consumed increases by 242 million lbs compared to the fixed wage only case. On the other hand, consumer welfare in the prunus market decreases even more in the transportation scenario, reflecting the loss of 324 million lbs of prunus consumed compared to the fixed-wage only case.

Though the pome and prunus industry react differently to the effect of the labor shortages on the transportation network, both lose significant welfare, including the gains they each had in the fixed-wage only outcome. In the pome industry, where producers lose \$413.1 million compared to a gain of \$239.2 million, it is the consumers gain in welfare that takes away from producer surplus because the outcome with transportation is slightly closer to the competitive equilibrium. In the prunus industry, the loss of \$27.7 million is because the huge decrease in sales can no longer be made up by the increase in price and the benefits of the lower wage.

Because wages and employment do not change for skilled or unskilled labor with transportation compared to without, the welfare for the skilled and unskilled labor markets are the same in both fixed wage scenarios. Nevertheless, the difference in welfare indicates how important it is to consider spoilage along the transportation network when accounting for the effects of a labor shortage. We find that firms benefit from the labor shortages when transportation is not considered, but these benefits turn to losses, particularly pronounced for the more price and time sensitive prunus industry, when transportation is considered. Firms in the pome industry have an economic surplus loss of \$179.0 million when the impacts of the slowdown in the transportation network are accounted for, in 1982–1984 dollars. Surplus loss for prunus is \$160.8 million. These are huge swings in firm welfare from the fixed-wage only case and the fixed-wage with transportation scenario.

5 Conclusion

Labor shortages in agricultural production have the attention of scholars, industry representatives, and the public alike. Unlike the literature focused on unskilled pre-harvest labor, we partition labor markets to focus on the economic impacts of skilled labor shortages and their relation to unskilled labor supply shocks. Additionally, we explicitly consider how those labor shortages exacerbate time for produce delivery by modeling the transportation network via a spoilage rate as a productivity parameter. We use data from the U.S. pome (apple) and prunus (peach) industries because their large value and wide geographic spread make them representatives for the overall agricultural sector.

After shocking the economy with a predicted 5.4% increase in output demand and a 7.0% decrease in unskilled labor supply, we compare the outcomes when wages are flexible and perfectly competitive to a scenario when wages are fixed at the pre-shock level. The shocks create pressure for unskilled and skilled wages to increase, but when wages are fixed, the industries must adjust by reducing employment. That creates labor shortages reaching 35% of the pre-shock employment because though employment is reduced, demand for labor remains high at the low fixed wage rate. The reduced employment also reduces output and creates a price premium. We estimate that the wage rigidity is creating a price premium amounting to 100% over the competitive price increase. The prunus market is less able to adjust to these shocks as its relatively price-elastic demand causes consumers to react to the price increase by switching to pome.

The labor shortages created by the fixed wage inefficiently distort the markets, creating dead-weight loss, and preventing the best and most efficient methods for the production and delivery of produce. These losses are $15.5 million in the output markets and $43.4 million in the labor markets in 1982–1984 dollars. But, we find these losses are borne by consumers and labor. Producer surplus sizably increases in both the pome and prunus industry as a result of the fixed wage creating a price premium that outweighs the decrease in sales.

The effects of the labor shortages are exacerbated when we explicitly account for commodity-specific spoilage along the transportation network. The difference in the outcomes is the effect of bottlenecks in the transportation sector leading to loss of value and marketing possibilities. Because prunus is more sensitive to time delays in delivery, labor shortages affect the prunus industry much more than the pome industry. However, when the effects of a labor shortage on the transportation network are accounted for, producer surplus in the output markets dramatically decrease. Thus in the scenario with transportation, producers lose the benefits from paying below competitive wages and share in the welfare losses with consumers and labor. These losses are large: 8% for pome and more than 30% for prunus compared to the case with no labor shortage. This demonstrates the importance of accounting for the transportation network as it explains why labor shortages are so relevant to producers.

If the predictions from Gallardo et al. (2014) are accurate, then the agricultural industries 1) whose demand is the most price sensitive and 2) whose spoilage rates are fastest or have the weakest transportation network will be the most affected. Economic losses can be large relative to the size of the industry, with unskilled labor, skilled labor, and consumers all suffering affects. Though we do not explicitly model time dynamics or international competition, it is not beyond the realm of plausibility to speculate the additional cost to consumers from these labor shortages could damage the marketability of U.S. produce both domestically as well as in overseas markers and also allow for the entry of foreign competition.

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A Two Stage Muth Model with Transportation Parameterization

We adopt Muth's (1964) model to analyze the effects of input supply shifts on industry output and input prices and quantities. Following Muth's model, we assume a representative producer of a homogeneous product using two inputs. The difference from Muth is that our inputs are skilled labor and unskilled labor. The producer is a price taker in the output and input markets. Under these conditions, the equilibrium of the industry may be described by the following equations:

$$Q = f(p) \tag{A.1}$$

$$Q = Q(L_s, L_u) \tag{A.2}$$

$$w_s = pq_s \tag{A.3}$$

$$w_u = pq_u \tag{A.4}$$

$$L_s = g(w_s) \tag{A.5}$$

$$L_u = h(w_u) \tag{A.6}$$

where Q is the final output of the commodity, the price per unit of the final product is p, L_s and L_u are skilled labor and unskilled labor inputs, the factor prices are w_s and w_u, and the marginal product of labor by skill type is given by q_s and q_u. Equation (A.1) is demand for the industry's output, (A.2) is the production function. Wages are given by the marginal product of each type of labor input as in (A.3) and (A.4). Finally, the factor supply facing the industry is given by (A.5) and (A.6).

By totally differentiating, we get:

$$-\frac{1}{\eta}\partial \ln Q + \partial \ln p = \gamma$$

$$\partial \ln Q - l_s \partial \ln L_s - l_u \partial \ln L_u = \delta$$

$$-\partial \ln p + \frac{l_u}{\sigma}\partial \ln L_s - \frac{l_u}{\sigma}\partial \ln L_u + \partial \ln w_s = \delta + \epsilon$$

$$-\partial \ln p + \frac{l_s}{\sigma}\partial \ln L_s - \frac{l_s}{\sigma}\partial \ln L_u + \partial \ln w_u = \delta - \frac{l_s}{l_u}\epsilon$$

$$-\frac{1}{e_s}\partial \ln L_s + \partial \ln w_s = \alpha_s$$

$$-\frac{1}{e_u}\partial \ln L_u + \partial \ln w_u = \alpha_u$$

where η is the price elasticity of the industry demand, γ is the relative increase in price at any given quantity on the new demand schedule (demand shift), l_s and l_u are the proportion of total receipts that are assigned to skilled labor input and unskilled labor input, σ is the elasticity of substitution between skilled labor input and unskilled labor input, δ is the factor-neutral productivity shift, ϵ shifts unskilled labor from a productivity shock, e_s and e_u are the price (wage) elasticities of skilled labor supply and unskilled labor supply, and α_s and α_u are the skilled labor supply shift and unskilled labor supply shift terms from a nontechnological change.

By adding a second output, the solution becomes:

$$Q^i = f(p^i, p^j) \tag{A.7}$$

$$Q^i = Q(L_s^i, L_u^i) \tag{A.8}$$

$$w_s = p^i q_s^i \tag{A.9}$$

$$w_u = p^i q_u^i \tag{A.10}$$

where i and j denote the commodities. Equilibrium wages are equal within skill types across commodities. The aggregate labor clearing conditions (A.5) and (A.6) remain as before. Total logarithmic differentiation of (A.7) through (A.10) gives:

$$-\frac{1}{\eta^i}\partial \ln Q^i + \partial \ln p^i + \frac{\kappa^{ij}}{\eta^i} = \gamma^i$$

$$\partial \ln Q^i - l_s^i \partial \ln L_s^i - l_u^i \partial \ln L_u^i = \delta^i$$

$$-\partial \ln p^i + \frac{l_u^i}{\sigma}\partial \ln L_s^i - \frac{l_u^i}{\sigma}\partial \ln L_u^i = \delta^i + \epsilon^i - \partial \ln w_s$$

$$-\partial \ln p^i + \frac{l_s^i}{\sigma}\partial \ln L_s^i - \frac{l_s^i}{\sigma}\partial \ln L_u^i = \delta - \frac{l_s^i}{l_u^i}\epsilon^i - \partial \ln w_u$$

where κ^{ij} is the asymmetric cross price elasticity for commodity i in response to a change in price of commodity j and σ is the symmetric elasticity of input substitution.

In order to model the transportation sector and the differential affects of it on pome and prunus, we use a specific functional form of technology. We use a constant returns to scale constant elasticity of substitution production function for pome and prunus. Thus the specific version of (A.8) we use is:

$$Q^i = [\theta((L_s^i)^{\Gamma_i})^\rho + (1-\theta)((L_u^i)^{\Gamma_i})^\rho]^{1/\rho} Z^\mu \tag{A.11}$$

where θ is the share parameter (equal across commodities) and $\rho = 1 - \frac{1}{\sigma}$ determines degree of substitutability of the two inputs. Z is any variable that shifts the production function. The parameter Γ_i is the commodity-specific productivity parameter. We think of the parameter Γ_i as a function of the commodity-specific decay or spoilage rate along the transportation network. If decay rate is higher, then Γ_i is lower since the same amount of labor delivers fewer output and thus can be seen as decrease in productivity. A more efficient transportation network increases Γ_i. We use our annual data averaged over occupations of the same skill-type to estimate Γ_{pome} and Γ_{prunus} as follows.

Under the equilibrium conditions in labor market:

$$\frac{\partial Q^i}{\partial (L_u^i)^{\Gamma_i}} = w_u = (1-\theta)[\theta((L_s^i)^{\Gamma_i})^\rho + (1-\theta)((L_u^i)^{\Gamma_i})^\rho]^{(1-\rho)/\rho}((L_u^i)^{\Gamma_i})^{(\rho-1)} Z^\mu. \tag{A.12}$$

With (A.11), (A.12), and $\sigma = 1/(1-\rho)$, we obtain:

$$\frac{Q^i}{(L_u^i)^{\Gamma_i}} = \left(\frac{1}{1-\theta}\right)^\sigma w_u^\sigma Z^{-\sigma}.$$

Table A.1. Spoilage and Transportation Productivity Estimates

	Pome	Prunus
Γ	1.01**	0.72***
R^2	0.47	0.65
RMSE	0.05	0.05

Notes: $\ln Q^i = constant + 1.1 \times \ln w_u + \Gamma^i \ln L_u^i + \varepsilon^i$. $N = 9$.
* $p < 0.01$; ** $p < 0.05$; *** $p < 0.01$

By taking the logarithm and rearranging we obtain the empirical production equations used in each commodity-specific model:

$$\ln Q^i = constant + 1.1 \times \ln w_u + \Gamma^i \ln L_u^i + \varepsilon^i \tag{A.13}$$

where $constant = \sigma \ln(1/(1-\theta))$, we have used $\sigma = 1.1$ from Card and Lemieux (2001), and ε^i captures non-conventional variables that shift the production function. By first applying the share of industry i output to the unskilled and skilled labor aggregate labor employed to get L_u^i and assuming a normal distribution for ε^i, we are able to calculate point estimates for the parameter value of Γ_{pome} and Γ_{prunus}. The results are in table A.1. The point estimate of Γ for pome is 1.01, and the estimate for prunus is 0.72, which confirms that prunus spoils more quickly than pome. We also test to confirm that θ is the same across commodities as our model requires. We cannot reject that they are different ($\chi^2(1) = 0.42$), which leads credibility to our model.

B Competitive Equilibrium Pre- and Post-Shock Detailed Results and Robustness

Tables B.1 and B.2 show the changes in the pre-shock competitive equilibrium of E1 in figure 1 to the post-shock competitive equilibrium at E3. As in the main text, we report the results for our preferred benchmark with $\sigma = 1.1$ as well as a robustness check when we vary σ to be 0.7 and 1.5 As the difficultly in substituting labor across skill-types increases from σ of 1.5 to 0.7, the impact of the shocks becomes larger because the industries cannot adjust to the shocks with employment composition but must instead adjust through wages of skilled labor.

The price of pome and prunus in the output markets increase by almost the same amount: 6.87% or about two cents per pound for pome and about 6.81% or 3 cents per pound for prunus. Yet though the price increases are about the same, output and sales decrease much more for prunus than for pome in percent terms. Sales of prunus decrease by 15 million pounds compared to the decrease of 3 million pounds of pome. Since the pome industry is about six times larger than the prunus industry, the percent change in the prunus industry is much larger, -1.43% compared to -0.05%. The reason that a similar sized price increase creates a much larger decrease in prunus sales is because the prunus industry is facing a relatively price elastic demand curve of -1.11 compared to the relative inelastic demand curve facing the pome market at -0.59. Thus consumers of pome are willing to adjust to the price increase whereas a prunus consumer is not. Therefore our results

Table B.1. Pre- and Post-Shock Commodity and Labor Equilibrium Percent Change

σ	Output	Output price	Skilled emp.	Skilled wage	Unskilled emp.	Unskilled wage
			(percent change)			
			Pome			
0.7	-0.13	7.03	3.46	1.90	-0.53	6.46
1.1	-0.05	6.87	4.46	2.77	-0.55	6.41
1.5	0.00	6.76	5.12	3.35	-0.56	6.38
			Prunus			
0.7	-1.59	6.96	1.95	1.90	-1.94	6.46
1.1	-1.43	6.81	3.02	2.77	-1.87	6.41
1.5	-1.32	6.71	3.72	3.35	-1.82	6.38

Notes: $e_s = 0.73$, $e_u = 3.37$, 5.4% final demand shock, and -7% unskilled labor supply shock.

Table B.2. Pre- and Post-Shock Commodity and Labor Equilibrium Level Change

σ	Output (mil. lbs)	Output price ($ / lbs)	Skilled emp. (ones)	Skilled wage ($ / hr)	Unskilled emp. (ones)	Unskilled wage ($ / hr)
			Pome			
0.7	-7.91	.02	1588.59	.18	-1100.96	.29
1.1	-3.04	.02	1552.43	.26	-1142.51	.29
1.5	0.00	.02	1527.58	.32	-1163.28	.29
			Prunus			
0.7	-16.41	.03	314.93	.18	-806.96	.29
1.1	-14.76	.03	308.15	.26	-777.85	.29
1.5	-13.62	.03	305.88	.32	-757.05	.29

Notes: $e_s = 0.73$, $e_u = 3.37$, 5.4% final demand shock, and -7% unskilled labor supply shock.

show the pome industry can better adjust to the increase in unskilled and skilled wages in the post-shock equilibrium.

That the pome industry adjusts better to the shocks is again seen in the labor markets. Despite the smaller loss of unskilled employment in the pome industry compared to the prunus industry in percentage terms, the pome industry hires more skilled labor in response to the shocks. This is because the output decrease is smaller for the pome industry than the prunus industry.

Though we use the best parameter estimates available from the literature, we also choose other parameters to see how robust our model results are to the parameters specified. Table B.3 shows the model's sensitivity to skilled labor supply elasticities ranging from 0.5 to 2. Though there are some small changes to output, prices, wages, and employment quantitatively, the qualitative result is robust. It is not surprising that as skilled-labor supply becomes more elastic, that skilled wage is less affected but skilled wage is more affected. This leads to a greater affect on output and price as expected and provides support for our model.

We test the effects when we vary the size of the decrease in unskilled labor supply and show the results in table B.4. When the decrease in unskilled labor is small such as 2%, then greater demand carries the day and output and prices increase along with wages and employment for both skill

Table B.3. Supply Elasticity for Skilled Labor Robustness Results

e_s	Output	Output price	Skilled emp.	Skilled wage	Unskilled emp.	Unskilled wage
			(percent change)			
			Pome			
0.50	-0.02	6.81	4.00	3.15	-0.47	6.40
0.73	-0.05	6.87	4.46	2.77	-0.55	6.41
1.50	-0.11	6.99	5.40	1.98	-0.72	6.43
2.00	-0.13	7.04	5.77	1.67	-0.79	6.44
			Prunus			
0.50	-1.37	6.76	2.60	3.15	-1.76	6.40
0.73	-1.43	6.81	3.02	2.77	-1.87	6.41
1.50	-1.55	6.92	3.89	1.98	-2.08	6.43
2.00	-1.59	6.96	4.23	1.67	-2.17	6.44

Notes: $e_u = 3.37$, $\sigma = 1.10$, 5.4% final demand shock, and -7% unskilled labor supply shock.

types. As that shock gets bigger, it increasingly overwhelms the positive demand shock, leading to outcomes where prices increase substantially even though output declines. In those scenarios, the loss of unskilled workers leads to large wage increase for both skill types and an increased role of skilled labor to take over unskilled occupations despite the difficulty of switching skill types.

We also test the model's sensitivity to the unskilled labor supply elasticities available from the literature in table B.4. Within a given level of decrease in unskilled labor, changing the unskilled labor elasticity from 3.37 to 2.24 does not change the results much considering how different in size these parameters are. Thus the results are fairly robust to the elasticity of the unskilled labor supply curve.

The results from these robustness checks indicate confidence in the model in that results change as expected. However the size of the decrease in unskilled labor supply plays a large and important role in the magnitude of the effects and those the welfare losses. Our welfare estimates are sensitive to the size of this shock relative to the demand increase shock.

Table B.4. Supply Elasticity for Unskilled Labor and Unskilled Labor Shock Robustness Results

Unskilled labor shift in	Supply elasticity for unskilled labor	Commodity	Output	Price	Skilled employment	Skilled wage	Unskilled employment	Unskilled wage
			(percent change)					
2%	2.24	Pome	1.46	3.67	0.66	4.40	1.98	3.75
		Prunus	1.98	3.68	1.19	4.40	2.06	3.75
	3.37	Pome	1.66	3.25	0.15	4.62	1.83	3.40
		Prunus	2.43	3.27	0.94	4.62	2.58	3.40
5%	2.24	Pome	0.61	5.48	2.81	3.48	0.36	5.26
		Prunus	0.05	5.46	2.22	3.48	-0.17	5.26
	3.37	Pome	0.63	5.42	2.74	3.51	0.40	5.21
		Prunus	0.11	5.40	2.19	3.51	-0.09	5.21
7%	2.24	Pome	0.04	6.69	4.25	2.86	-0.43	6.26
		Prunus	-1.24	6.63	2.92	2.86	-1.65	6.26
	3.37	Pome	-0.05	6.87	4.46	2.77	-0.55	6.41
		Prunus	-1.43	6.81	3.02	2.77	-1.87	6.41
11%	2.24	Pome	-1.10	9.10	7.11	1.63	-2.02	8.27
		Prunus	-3.81	9.00	4.29	1.63	-4.61	8.27
	3.37	Pome	-1.42	9.76	7.90	1.29	-2.45	8.82
		Prunus	-4.52	9.65	4.67	1.29	-5.43	8.82

Notes: $\sigma = 1.10$, $e_s = 0.73$, and 5.4% final demand shock. Supply elasticity of 2.24 is from Rosenbloom (1991) and 3.37 is from Perloff (1991).